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FUTURE AIRCRAFT TECHNOLOGY ENHANCEMENTS – BLOCK I

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FINAL REPORT FOR 05/22/1997 – 10/30/1997

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13. ABSTRACT *(Maximum 200 words)*

The intent of the contracted study was to identify technologies having highest potential of helping achieve the Fixed Wing Vehicle Program sub-area goals. A subset of the activity was to identify technologies that need flight test on a new vehicle to further the validation. The contract effort defined the technologies and suggested a modular vehicle that could be used to flight validate promising technologies. Benefits of the selected technologies, applied in combination with each other, were identified. A rough-order-of-magnitude (ROM) cost estimate was prepared for a possible follow-on Block II program to construct and flight test the demonstrator vehicle.

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FATE--Block 1--Phase 1

This report documents work performed by Boeing-Phantom works for Wright Laboratory, Dayton, Ohio in response to contract F33615-97-C-3806. The period of performance was 30 June 1997 through 30 October 1997. Capt. Mark Cherry (WL/FI) was the Program Manager, Mr. Tom Black (WL/FI) was the Technical Manager, and Mr. Dave Brown (WL/FI) was the Technical Monitor. Mr. Jim Cupstid was the Boeing-Phantom Works Program Manager. The Boeing technical team included Dr. Ray Cosner, Dr. John Corrigan, Mr. Charles Saff, Mr. Jerry Amies and Mr. Kevin Aleshire. The Quality Functional Deployment effort was facilitated by Mr. Gary Gill, Mr. Dave Hamilton and Mr. Matt Vance.

This report is organized as indicated on the facing page.

Future Aircraft Technology Enhancements (FATE) Block I---Phase 1

Page

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FWV Demonstration Program

This contract was awarded in response to a PRDA titled Fixed Wing Vehicle (FWV) Demonstration Program. The PRDA identified seven major objectives. The Phase 1 activity addressed the first three objectives. Phase 2 of the program would have addressed the final four objectives, however, WL/FI chose to not proceed with Phase 2 in favor of transitioning to the UCAV-ATD program.

FWV Demonstration Program
PRDA 97-02-FIK

OBJECTIVES

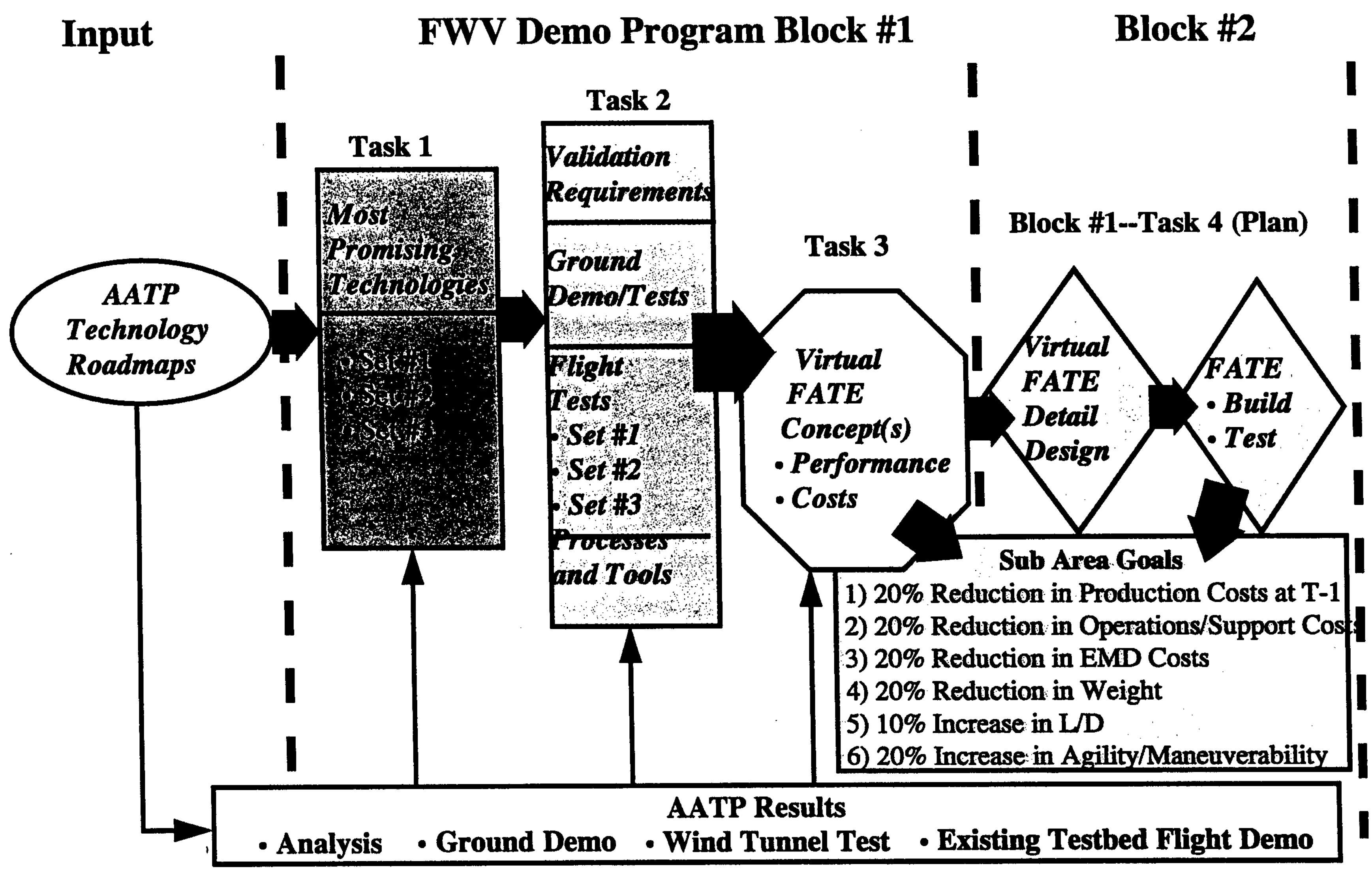
- Define A/C Technologies Having Highest Potential of Helping Achieve the Fixed Wing Vehicle Sub-Area-Goals
- Suggest Needed CRAD or IRAD programs Necessary to Mature High Payoff Technologies
- ID Technologies Needing Flight Test Validation in a New Vehicle to Reduce Risk
- Define a Modular FATE 1 Uninhabited Vehicle Needed to Flight Validate Promising Technologies
- Quantify Benefits of High Payoff Technologies Singly and in Combination
- Define a Block II Program to Design, Build, and Test the FATE 1 Vehicle
- Estimate the Cost of the Block II Program

FWV Technology Validation--Approach

The Boeing-Phantom Works approach to the program consisted of four tasks. The Fixed Wing Vehicle Advanced Airframe Technology Plan (AATP) was used to identify the technologies that were input to the validation approach.

Task 1 was used to define the technologies in the AATP that provided the most promise in achieving the FWV Sub Area Goals. In Task 2, the requirements for validating the most promising technologies up to a Technology Readiness Level (TRL) of Six was determined. In Task 3 we would define an unmanned FATE vehicle design and use it to assess the impact of the most promising technologies, individually and collectively, on the Sub Area Goals. Task 4 was devoted to developing a plan for Block 2 of the program. In Block 2, the contractor would conduct the detail design, build and test the FATE vehicle.

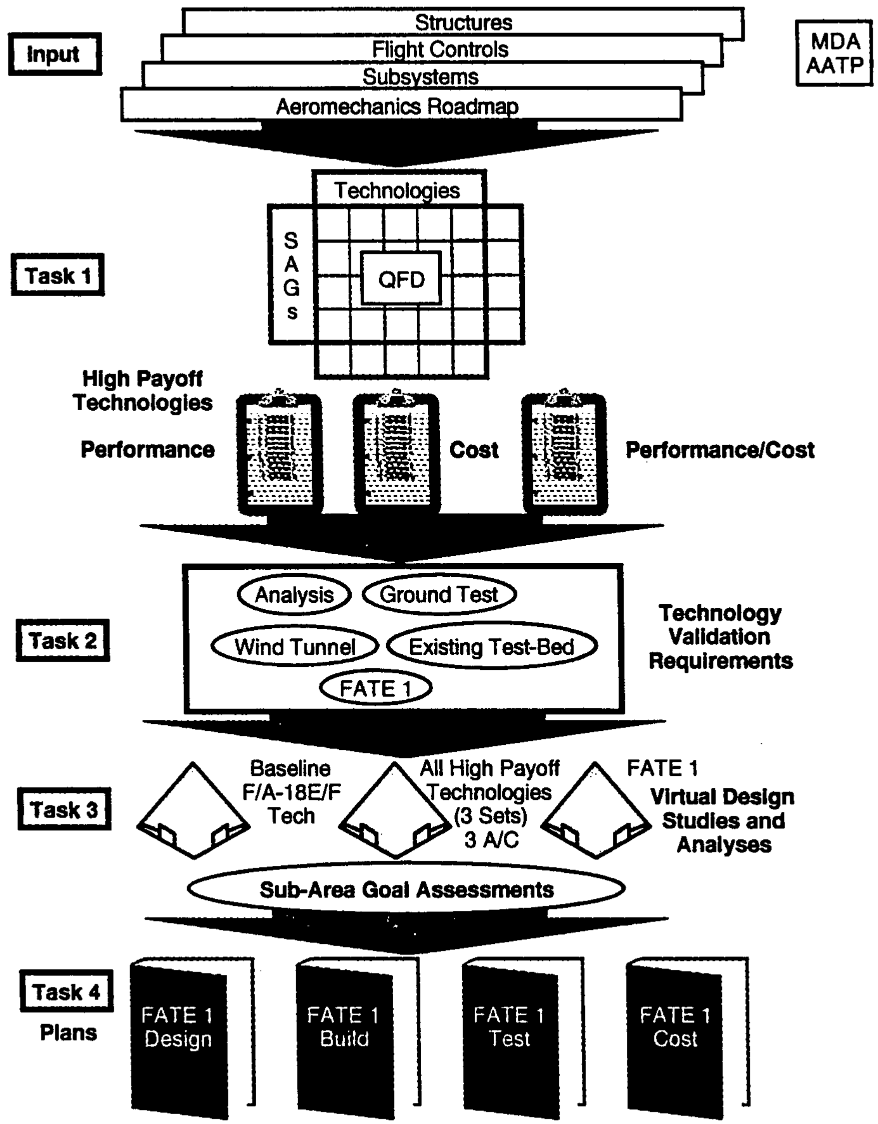
FWV Technology Validation--Approach



Technical Program Flow

The flow of the Block 1 technical effort is illustrated. The AATP provides the capability to define the input technologies for each of the four FWV thrust areas. A Quality Functional Deployment (QFD) assessment is used in Task 1 to identify the most promising technologies relative to the FWV Sub Area Goals. Three sets are identified. The first set is those technologies that maximize the FWV performance goals, the second set minimize cost and the third set provides the best combination of performance and cost. The validation requirements are identified in Task 2 for each promising technology. These requirements fall in one of five categories in order to reach a TRL of Six. In Task 3, virtual FATE vehicle designs are used to assess each promising technology relative to its impact on the Sub Area Goals. Finally, plans are defined in Task 4 for the Block 2 effort. These plans include detail design, build, test and cost.

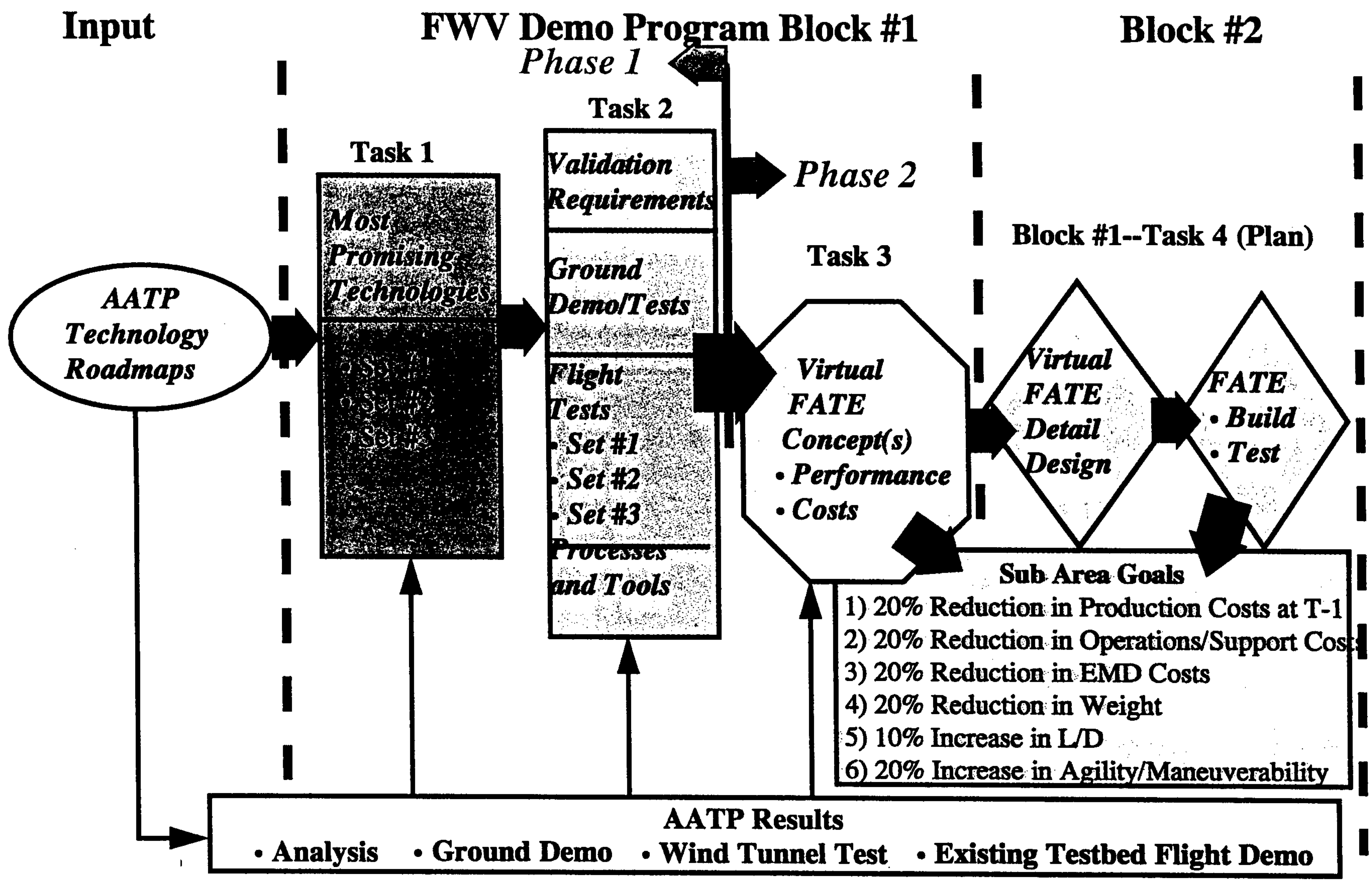
Technical Program Flow



FWV Technology Validation--Approach

WL/FI elected to break the FWV Block #1 activity into two phases. Phase 1 covers the first two tasks of Block #1 and Phase 2 covers Tasks 3 and 4. As indicated earlier, WL/FI elected not to continue with Phase 2 and thus this report covers only Tasks 1 and 2.

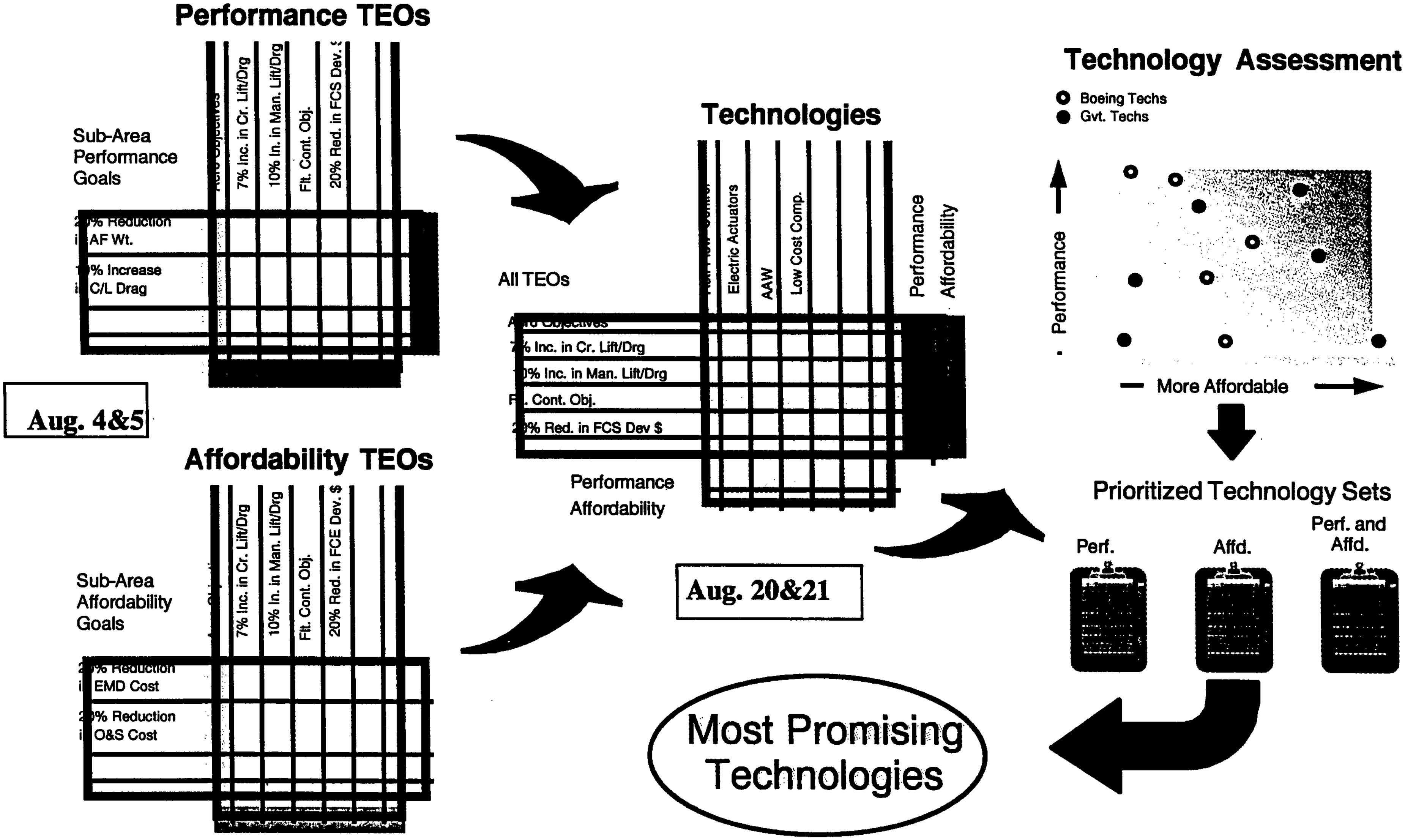
FWV Technology Validation--Approach



Quality Function Deployment (QFD)

QFD was used in Task 1 to select the FWV technologies having the most promise of achieving the FWV Sub Area Goals. This Task was accomplished in two sessions at WPAFB. The first session was held on 04 and 05 August '97 in which the Technical Element Objectives (TEOs) were related to the Sub-Area Goals to determine which TEOs had the most impact on each Sub Area Goal. The second session was held on 20 and 21 August when a list of 44 technologies, jointly developed by WL/FI and Boeing-Phantom Works, were evaluated to assess the impact of each technology on each TEO. These results, when combined with the results of the first session, provided the capability to assess the impact of each technology on each Sub Area Goal. These results were then used to establish three prioritized sets of technologies. The first set identifies those technologies that show the best promise of achieving both the affordability and performance goals. The second set shows the most promise of achieving the affordability goals and the final set the most promise of achieving the performance goals. A detailed discuss of the QFD assessment is provided in this report beginning on page 27.

QFD was the Basis for the Selection of Most Promising Technologies



WL/FI QFD Participants

The QFD assessment was conducted with participation by WL/FI along with the four Boeing-Phantom Works FWV technology thrust area leaders.

WL/FI QFD Participants

Al Basso	John Leuggers
Tom Black	Dieter Multhopp
Dave Brown	Jerome Pearson
Capt. Mark Cheney	David Pratt
Dick Colclough	Jim Tuss
Dudley Fields	Brian VanVliet

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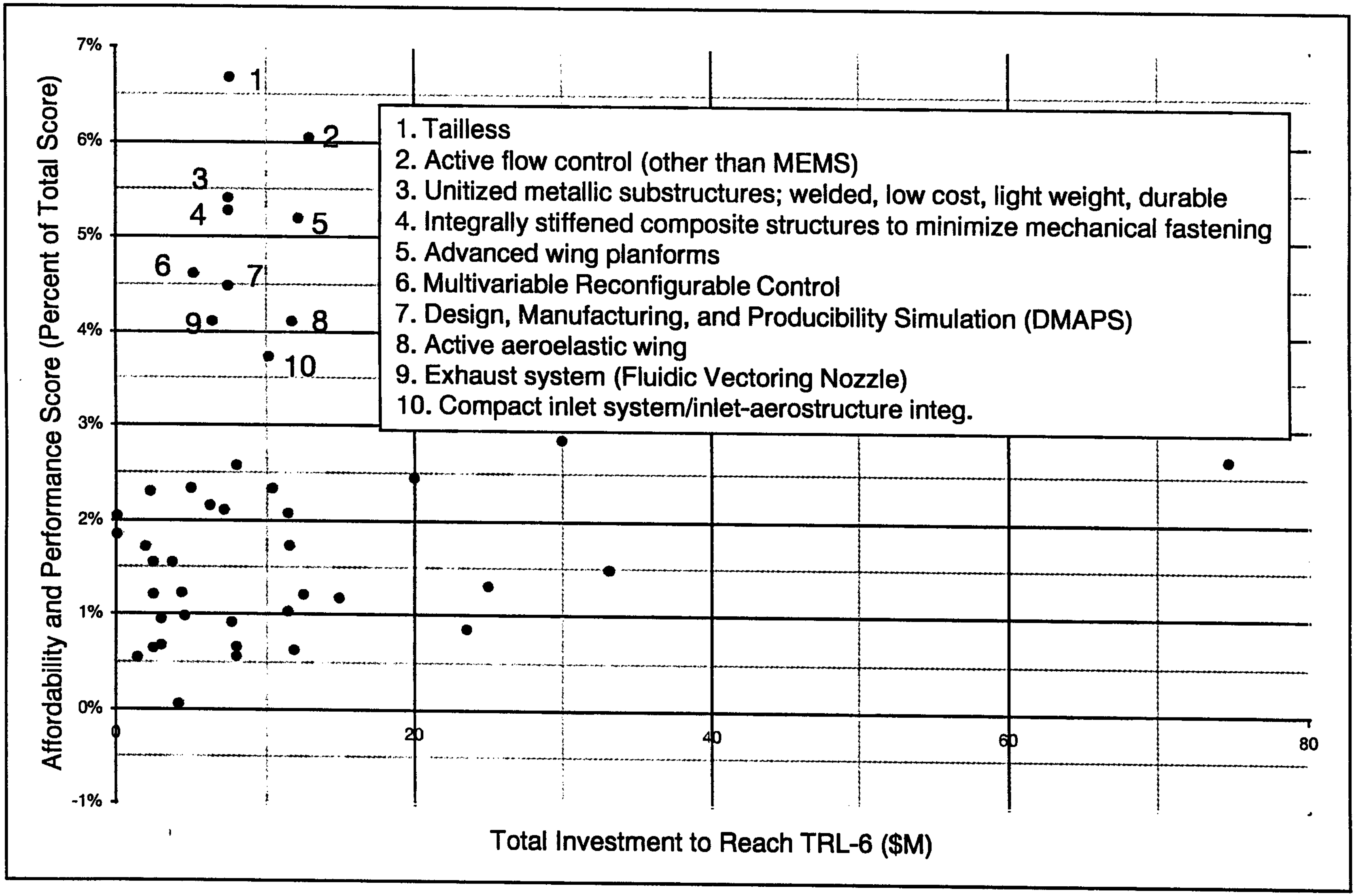
Affordability + Performance Map

This chart identifies the ten technologies showing the most promise in achieving the cost and performance goals. The % of the total QFD score achieved by each of the technologies is plotted as a function of the investment costs required to reach a Technology Readiness Level of Six for each technology. The top ten technologies not only have the highest score but also have competitive investment requirements.

Affordability + Performance Map

Investment to reach TRL 6 vs.
Affordability and Performance Perspective



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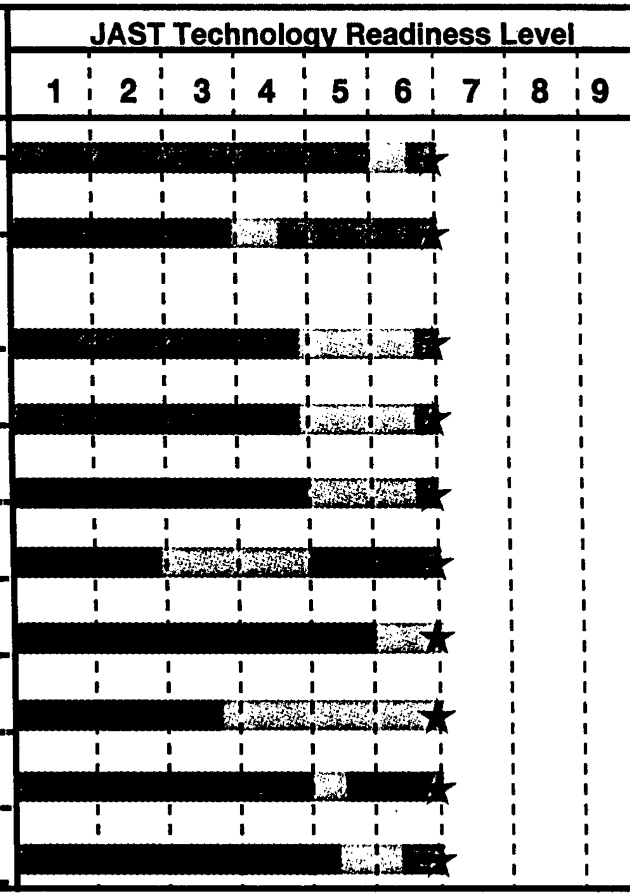
Technology Validation Requirements Top Ten Affordability/Performance Technologies

This chart summarizes the results of the Task 2 effort for the top ten technologies from the previous chart. In Task 2, the type of demonstration required to validate each top ten technology to a TRL of Six was determined along with the funded as well as unfunded investment requirements necessary to reach TRL #6. These assessments were based on the current Boeing-Phantom Works AATP. The required unfunded programs are identified in the AATP.

The investment requirements for those technologies that require flight testing on a new test aircraft such as FATE do not include the cost of the new vehicle. Boeing-Phantom Works didn't want try to spread the cost of the vehicle across the technologies. Thus, two investment requirements are stated for the two structures technologies. The higher investment is required to conduct a ground demonstration to validate the technology. The lower investment would be required if the structure technology were validated in a new uninhabited vehicle such as FATE. This lower investment is more appropriate for comparison with the other top ten technologies such as Tailless or Adv. Wing Planforms that require validation on a new vehicle.

Technology Validation Requirements Top Ten Affordability/Performance Technologies



High Payoff Technologies -- Costs	Demo Required	Required Investment $M Funded	Required Investment $M Unfunded
Tailless	Flt Test (N)	5.42	2.24
Active Flow Control (Other Than MEMS)	Flt Test (N)	2.65	10.30
Unitized Metallic Substr.	Grnd Test	6.5-46	1.0-3.0
Integ. Stiffened Comp. Str	Grnd Test	6.5-46	1.0-3.0
Adv. Wing Planforms	Flt Test (N)	10.46	1.69
Multiv. Reconfig Ctrls	Flt Test (N)	1.20	4.00
DMAPS	Analysis	7.5	0.00
Active Aeroelastic Wing	Flt Test (E)	11.8	0.0
Ex. Sys Fluidic Vect Nzl	Flt Test (N)	1.85	4.64
Compact Inlet System	Flt Test (N)	6.13	4.20
	Total	60.01 to 139.01	29.07 33.07

LEGEND

Technology Readiness Level
- Jan. '97
- Desired (2001First Flt.)
- Funded
- Unfunded

(C)--Flight Test Complete

(E)--Existing Test Aircraft

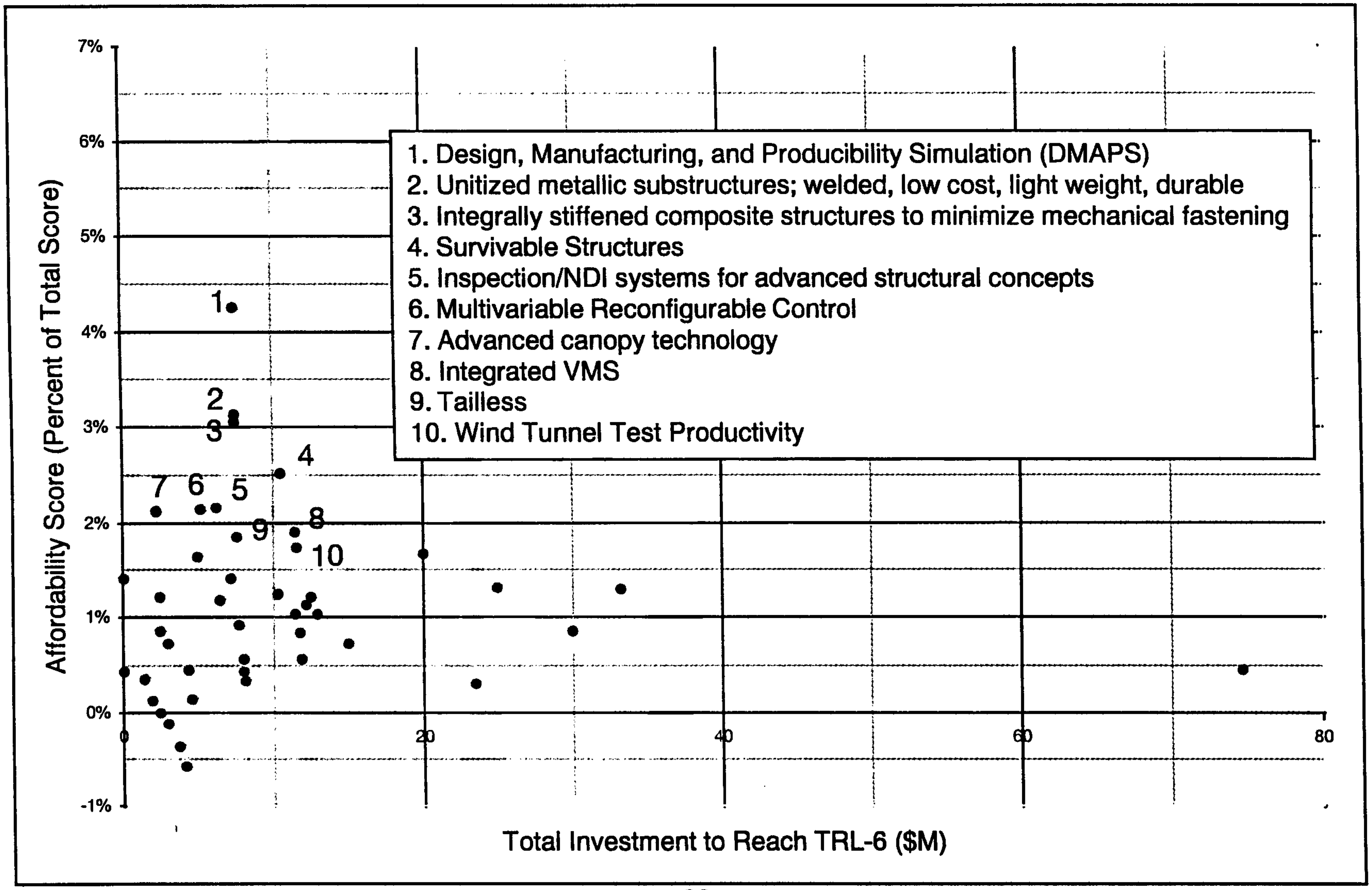
(N)--New Test Aircraft Needed

Affordability Only Map

This chart identifies the top ten technologies from the QFD assessment showing the most promise in achieving the three affordability goals. Note that four of the top five technologies are related to structures. Also note that the #1 and #10 technologies deal with processes and tools.

Affordability Only Map

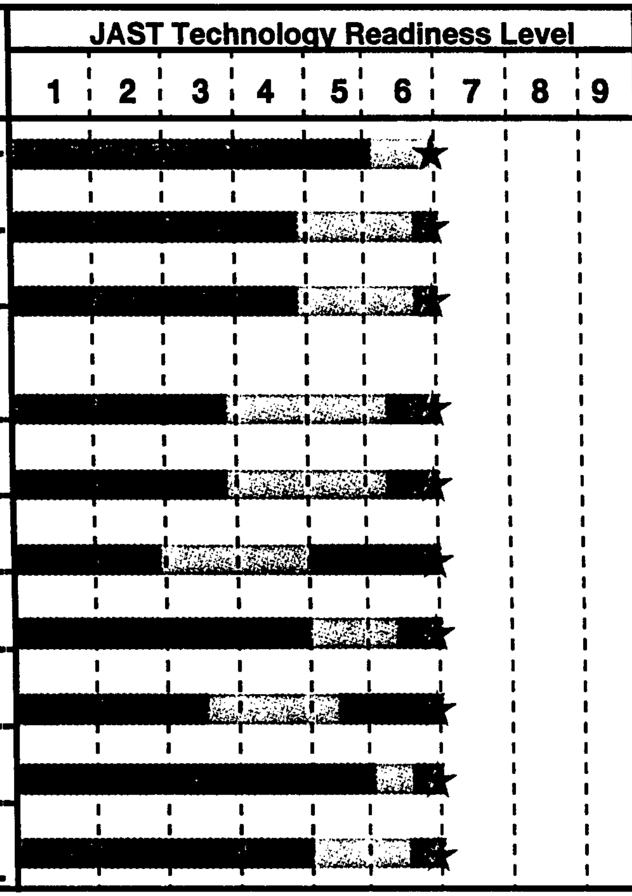
Investment to reach TRL 6 vs.
Affordability Perspective



Technology Validation Requirements Top Ten Affordability Technologies

The Task 2 results for the top ten affordability technologies are shown in this chart. Note that the Design Manufacturing and Producibility Simulation technology will be validated through analysis. These processes and tools will be used during the FATE or UCAV-ATD design and build activities. The results will be tracked and compared to baseline processes and tools to validate the DMAPS cost and cycle time benefits. The Wind Tunnel Test Productivity processes and tools will be validated during wind tunnel test activities.

Technology Validation Requirements Top Ten Affordability Technologies



High Payoff Technologies -- Costs	Demo Required	Required Investment $M Funded	Required Investment $M Unfunded
DMAPS	Analysis	7.5	0.00
Unitized Metallic Substr.	Grnd Test	6.5-46	1.0-3.0
Integrally Stiffened Composite Structure	Grnd Test	6.5-46	1.0-3.0
Survivable Structure	Grnd Test	8.5	2.0
Inspection/NDI Systems	Grnd Test	4.8	1.5
Multiv. Reconf. Cntrl	Flt Test (N)	1.20	4.00
Adv. Canopy technology	Fl Tst (N/E)	1.6	0.7
Integrated VMS/Diagn.	Flt Test (N)	4.0	7.5
Tailless	Flt Test (N)	5.42	2.24
Wind Tun. Test Prod.	Grnd Test	8.03	3.61
	Total	54.05 to 133.05	23.55 27.55

LEGEND

Technology Readiness Level
- Jan. '97
- Desired (2001First Flt.)
- Funded
- Unfunded

(C)--Flight Test Complete

(E)--Existing Test Aircraft

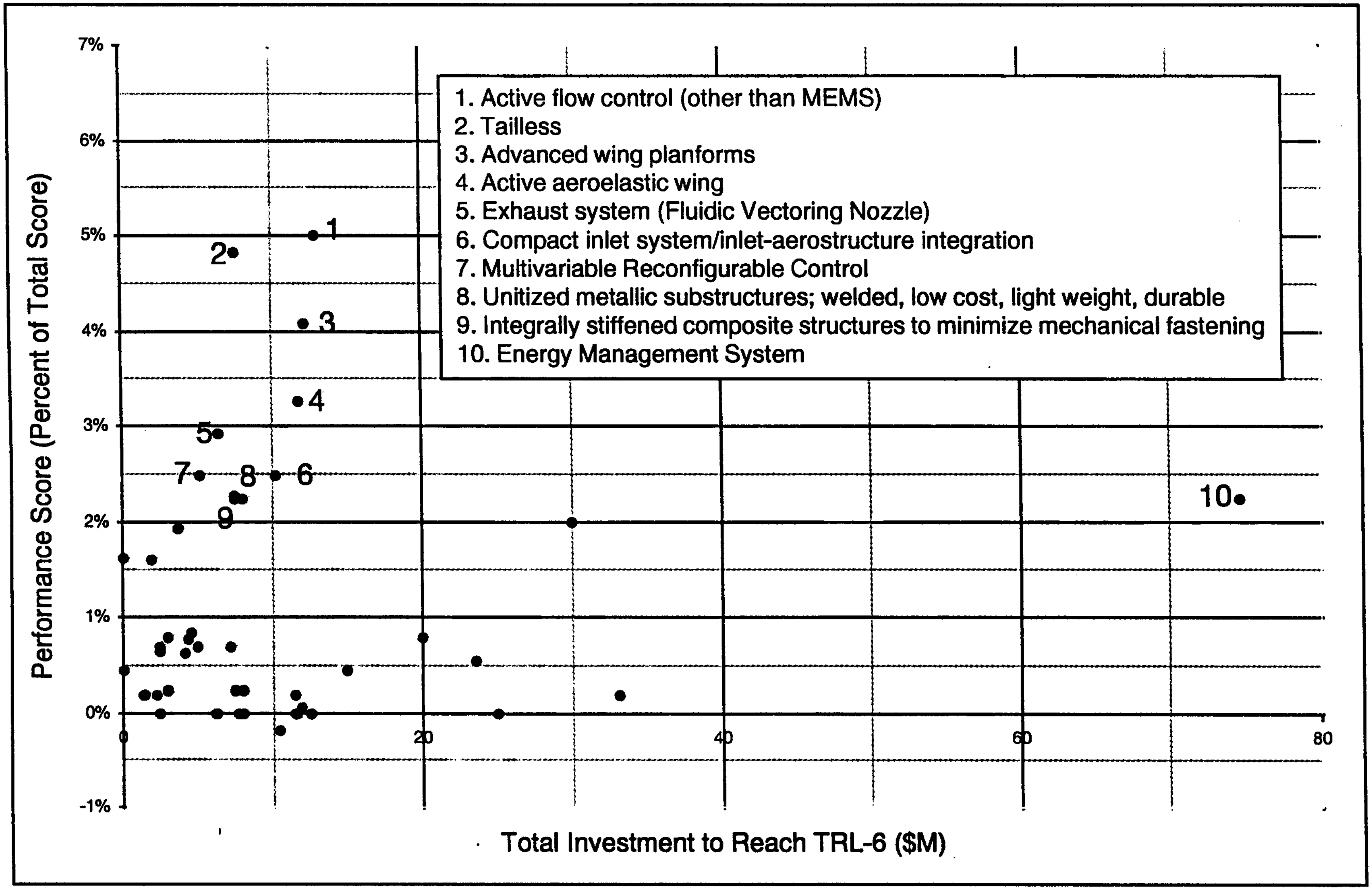
(N)--New Test Aircraft Needed

Performance Only Map

This chart identifies the most promising technologies from the QFD assessment of the performance goals including weight. The order is different but the technologies making this list are similar to those on the previous two list. The notable exception is the Energy Management System. This technology has a high investment cost compared to other technologies, however, it includes several sub-technologies in addition to the J/IST (TEMM) such as advanced fuels and light weight heat exchangers. In addition, these investments might be adequate to validate to a TRL of Six without flight test.

Performance Only Map

*Investment to reach TRL 6 vs.
Performance Perspective*



Technology Validation Requirements Top Ten Performance Technologies

The validation requirements for the top ten performance technologies are shown. Although flight testing in a new aircraft is shown as a requirement for the Energy Management System, the J/IST investment of $50M, included in the $71.5M total, may be adequate to validate the TEMM to TRL #6 without going to the expense of a flight test program.

A detail discussion of the QFD assessment, leading to these summary results, follows.

Technology Validation Requirements Top Ten Performance Technologies

High Payoff Technologies -- Performance	JAST Technology Readiness Level (1 2 3 4 5 6 7 8 9)	Demo Required	Required Investment $M Funded	Required Investment $M Unfunded
Active Flow Control (Other Than MEMS)		Flt Test (N)	2.65	10.30
Tailless		Flt Test (N)	5.42	2.24
Adv. Wing Planforms		Flt Test (N)	10.46	1.69
Active Aeroelastic Wing		Flt Test (E)	11.8	0.0
Ex. Sys Fluidic Vect Nzl		Flt Test (N)	1.85	4.64
Compact Inlet System		Flt Test (N)	6.13	4.20
Multiv. Reconf. Ctrl.		Flt Test (N)	1.20	4.00
Unitized Metallic Substr.		Grnd Test	6.5 - 46	1.0 - 3.0
Integ. Stiffened Comp. Str		Grnd Test	6.5 - 46	1.0 - 3.0
Energy Mgmt. Syst.		Flt Test (N)	71.5 (1)	3.2
		Total	124.01 to 203.01	32.27 to 36.27

LEGEND

Technology Readiness Level
- Jan. '97
- Desired (2001First Flt.)
- Funded
- Unfunded

(C)--Flight Test Complete

(E)--Existing Test Aircraft

(N)--New Test Aircraft Needed

(1) Energy Management Systems includes J/IST TEMM costs as shown, SITE-M, Integrated Thermal Energy Management and Advanced Fuels.

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Quality Function Deployment Applied to FWV

This package is divided into three sections.

A brief QFD process overview is offered to acquaint the reader with Boeing St. Louis' use of this decision tool.

The plotted results are presented after the QFD discussion.

Finally, the rationale supporting the 14 leading technologies is presented.

Quality Function Deployment Applied to FWV

- **Process Overview**
- Results
- Conclusions

QFD is Documented in a "House of Quality"

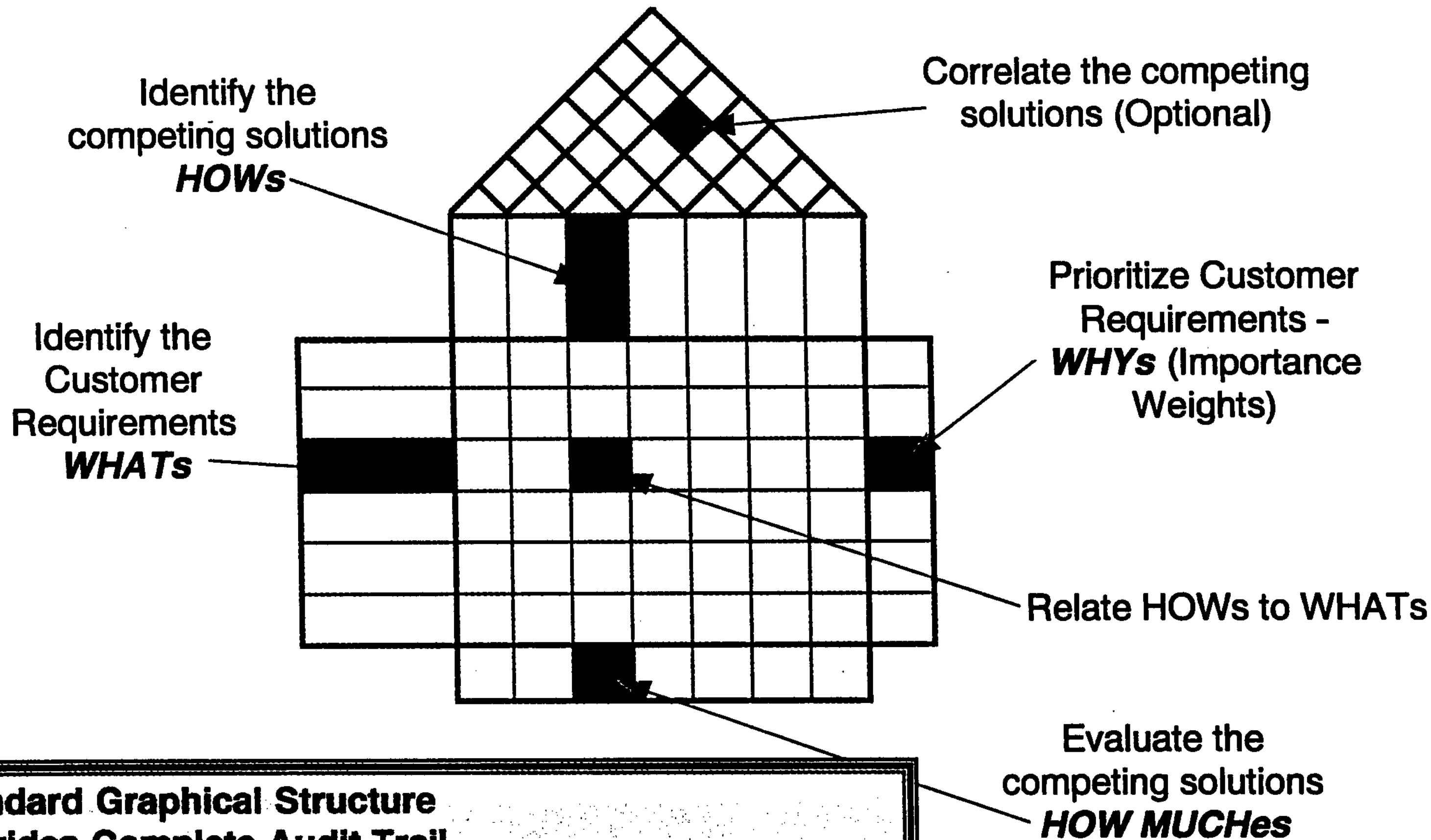
The Boeing St. Louis FWV team has based the FWV technology prioritization process on a widely accepted system engineering tool known as Quality Function Deployment (QFD).

QFD is a popular and accepted tool used by industry to facilitate interdisciplinary interaction to identify the best overall solution to a stated problem. QFD is a structured, matrix-based process for exploring solutions to complex problems with negotiable aspects. A key attribute is its ability to document the decision process, thus providing an audit trail. The key to a successful application of QFD lies in the collaborative capturing of accurate definitions for each element that populates each axes of each matrix.

The process normally is completed in a sequential series of steps starting with the "WHATs". For the final matrix in the FWV technology prioritization, the "WHATs" are the Technology Element Objectives (TEO) and the "HOWs" are the set of technologies. The priority of the TEOs, completed at the 4-5 Aug 97 customer / Boeing STL meeting, was withheld so as to not influence the prioritization of the technologies completed at the 21-22 Aug 97 customer / Boeing STL meeting.

The matrix-based format of QFD also allows examination of a project at increasing levels of detail. The outputs of one matrix can be mathematically liked to the inputs of a following matrix. The FWV QFD linked three matrices together in this manner.

QFD is Documented in a "House of Quality"



- **Standard Graphical Structure**
- **Provides Complete Audit Trail**
- **Rooms Tailored to Fit Needs**
- **Basis for a Family of Charts for Relationship Flowdown**

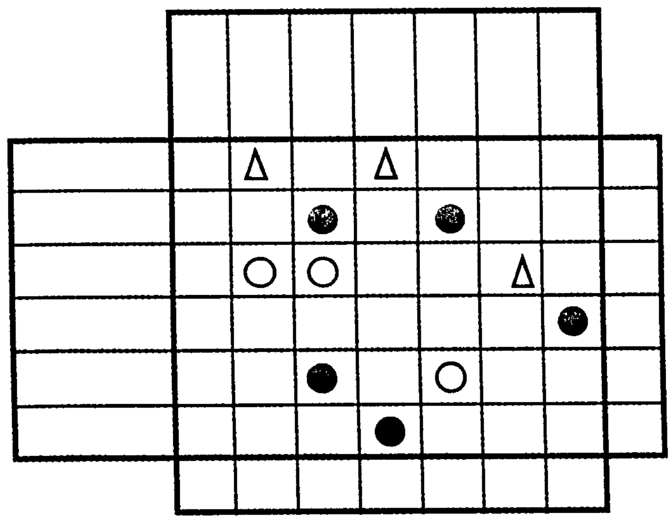
Relationship Matrix Uses Symbols to Relate HOWs to WHATs

Once the project is mapped into a QFD matrix format and each axis element identified and defined, the relationships inside each matrix can be scored.

Typically the scores capture the intensity of how well a solution option is able to satisfy an objective. Direct contributions are first assessed, then the strength of the contribution.

The QFD process emphasizes drivers ("STRONG" s) and discussion should focus on those matrix cells where there is disagreement on whether or not a "STRONG" score should be assigned. Discussing "MODERATE" s verses "WEAK" s is of limited value. There is no value in discussing a "WEAK" verses a "NONE".

Relationship Matrix Uses Symbols to Relate HOWs to WHATs



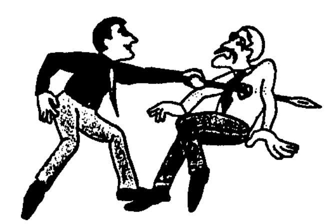
Relationship Symbols	
	None (White)
Δ	Weak (Green)
○	Moderate (Blue)
●	Strong (Red)

The Relationship Symbol Indicates:

- Whether the HOW Directly Contributes to the Satisfaction of the WHAT
- and if So, the Relative Strength of the Relationship

Discussion Ground Rules:

Strong Vs. Lower Relationships - Useful
Moderate Vs. Lower Relationships - Limited
Weak Vs. Lower Relationships - None

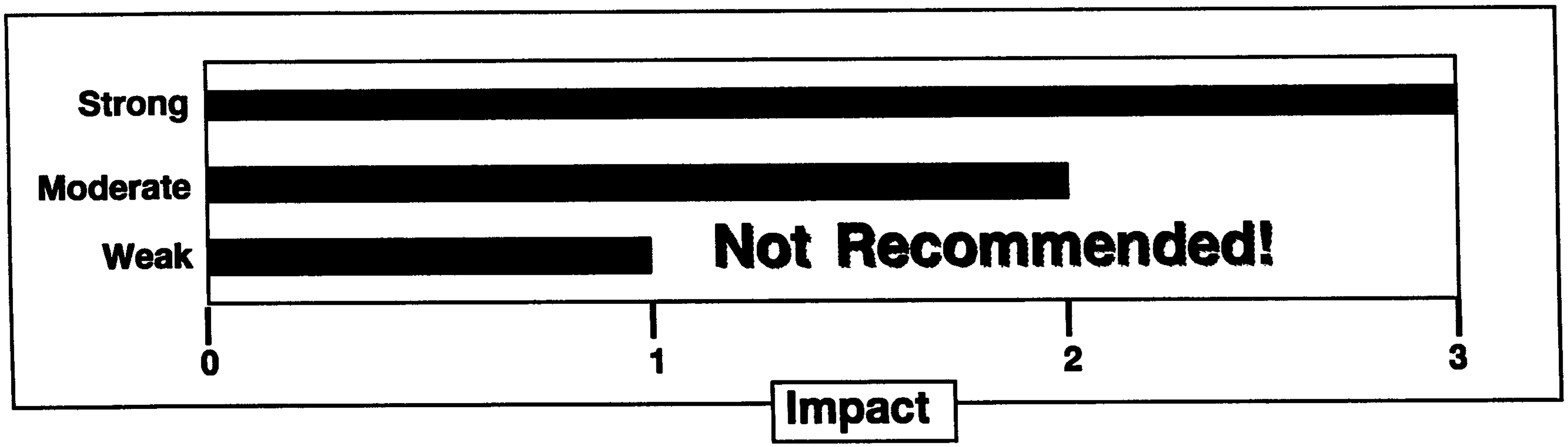


Relationship Values for Weak, Moderate, Strong?

A numerical score is also associated with the "WEAK", "MODERATE", "STRONG" assessments.

One perspective would be to associate a linear numerical philosophy. Linear scoring is not recommended because this philosophy does not illuminate the drivers ("STRONG"s) as well as a non-linear scoring philosophy.

Relationship Values for Weak, Moderate, Strong?



Matrix is completed with the philosophy that there is a linear relationship between Weak, Moderate, and Strong

Linear scoring does not illuminate the drivers

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1, 3, 9 Relationship Values are Better

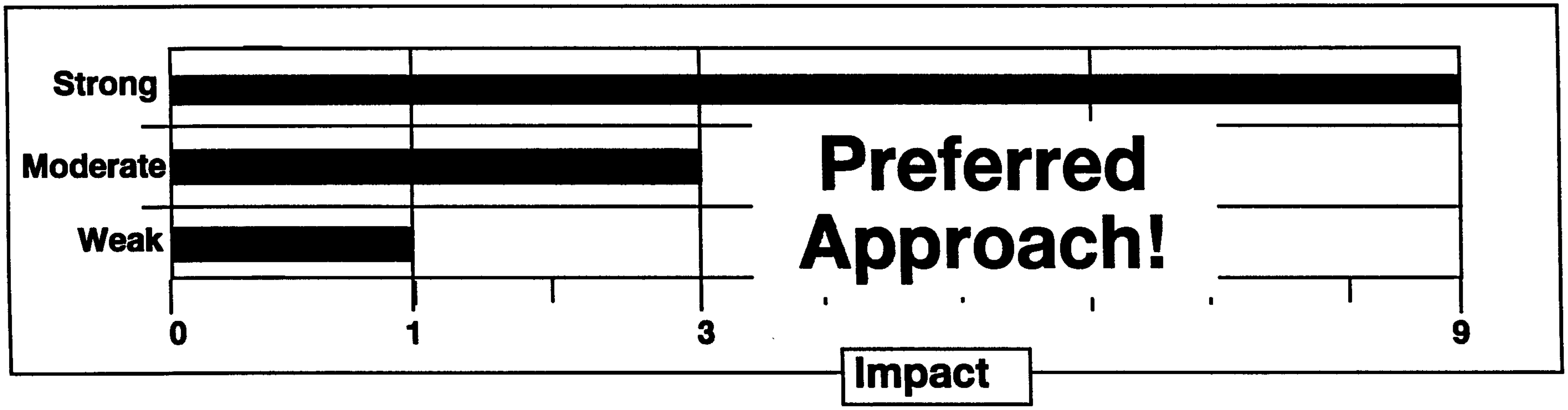
The preferred, traditional QFD numerical scores are:

NONE	*= 0*
WEAK	*= 1*
MODERATE	*= 3*
STRONG	*= 9*

This philosophy demands that you feel a "STRONG" relationship is 3 times more valuable than a "MODERATE" and 9 times more valuable than a "WEAK".

The 0, 1, 3, 9 philosophy will illuminate those "HOW"s that strongly satisfy "WHAT"s. This is the scoring philosophy Boeing STL has successfully employed, and it is also the accepted QFD standard. This philosophy was used when scoring the three FWV QFD matrices.

1, 3, 9 Relationship Values are Better



Matrix is completed with the philosophy that:
Strong is 3 times more significant than Moderate and 9 times more significant than Weak

Nonlinear scoring emphasizes the drivers

QFD Math is Simple!

QFD math is simple and easy!

To compute a relative priority simply multiply the array of "WHAT" weights with the array of any "HOW" scores and sum these products.

For ease of interpretation the raw scores are usually scaled to 100. In the example, the raw score of 93 represents 61% of the total output emphasis.

This non-FWV example also illustrates the importance of the word relative. The computed priorities are only relative to the group of potential solution options ("HOWs") that were scored against the objectives ("WHATs"). If a solution option is missing, the computed priorities will not change but the scaled priority may be different once that omission is corrected. The relative priority of one solution over another is an important QFD output concept.

QFD Math is Simple!

- Relationship Weights Generally are 1,3, and 9 for Qualitative Assessments
- Actual Values May be Used in the QFD Matrix, if Available
- This May be the Case for Matrix 2 in the FWV Process

Relationship Weights

Weak	△	= 1
Moderate	○	= 3
Strong	●	= 9

	25% Reduction in Landing Gear Weight	20% Reduction in Structural Weight	25% Reduction in Duct Inlet Weight and Volume	Relative Importance
20% Reduction in EMD Cost		○		8
10% Inc. in Cruise Lift/Drag			○	10
20% Red. in Airframe Weight	△	●	○	7
20% Inc. in Agility / Maneuver		△		6
Raw Score	7	93	51	(151)
Scaled to 100	5 %	61 %	34 %	

93 / (7 + 93 + 51)

(3 x 8) + (9 x 7) + (1 x 6)

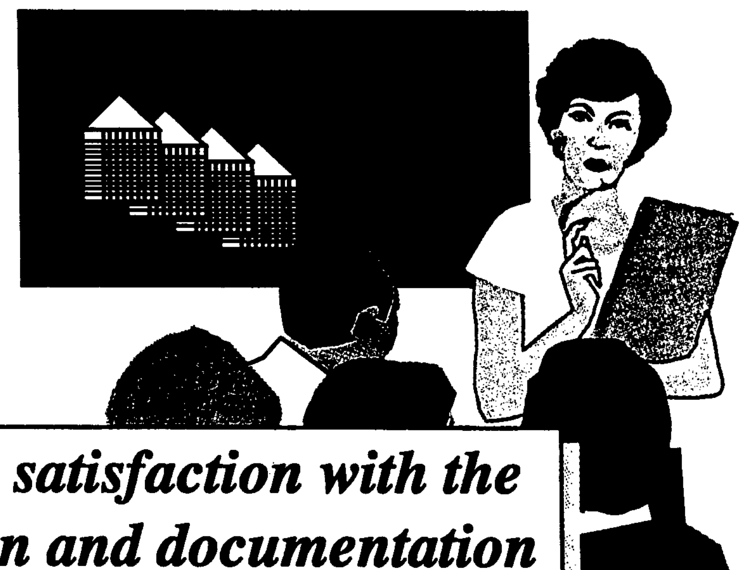
Please Remember QFD is a Method - Not a Panacea

Keep in mind that QFD is a process, and like all processes, the outputs are only as good as the inputs.

QFD offers qualitative guidance which is only as reliable as the inputs provided by the team. It should not be viewed as a one-time-pass which produces doctrine, rather it is a continuos process which can provide guidance and insight at every stage.

Please Remember QFD is a Method - *Not* a Panacea

- QFD *is:*
  - a matrix-based decision analysis tool
  - a structured, problem-solving process for exploring solutions to complex problems
  - a means of capturing ***expert judgment*** in order to prioritize options
  - based on a team approach
- QFD *is not:*
  - a black box
  - a software package
  - the "answer"



Customers repeatedly express satisfaction with the enhanced team communication and documentation

Boeing has Extensive Experience in QFD Application to Technology Prioritization

Boeing-Phantom Works has formally applied the QFD process to over 125 applications over the last six years. The first formal application, completed in a non-production environment, was an Internal Research and Development (IRAD) technology prioritization effort.

Over the years we have gained experience with this specific type of application, i.e., prioritizing technologies. Highlighted here are some of the more significant QFD efforts that were either explicitly designed to prioritize technologies or could have easily fed a technology prioritization.

Boeing has Extensive Experience in QFD Application to Technology Prioritization

- MDA Strategy to Technology for IRAD Prioritization
- MDA SOF Requirements and Technology Prioritization
- JAST Strategy-to-Task-to-Technology (JAST PO)
- JAST CDA Technology Prioritization (MDA/NGC/BAe)
- JAST Training/Mission Management Technology Prioritization (JAST PO)
- Common Support Aircraft Requirements
- NATO AGARD Mobility Technology Prioritization
- NATO AGARD Weapon Technology Prioritization
- Progressive Response Functional Prioritization (J8)
- POM-98 DoN Warfare Task Prioritization
- NASA Policy Deployment for International Space Station Benefits
- Cruise Missile Defense Integrated Product Team (SAF/AQPT)
- IHPTET Goal Prioritization (JAST PO)
- Joint Service Advanced Flight Control Technology Prioritization
- High L/D Fighter Technology Prioritization

Quality Function Deployment Applied to FWV

This section will successively walk through each result chart that was used to identify the top 14 technologies for the FWV program.

Definitions of what was considered and what was not considered under this program are offered first.

The overall QFD architecture is then presented followed by output charts produced at each step in that architecture.

The investment cost estimates to reach a Technology Readiness Level (TRL) 6 by the 2003 technology maturation date are presented next.

Finally, the overall QFD outputs are married with the investment cost estimates, in two different ways, to produce a prioritized listing of FWV technologies.

Quality Function Deployment Applied to FWV

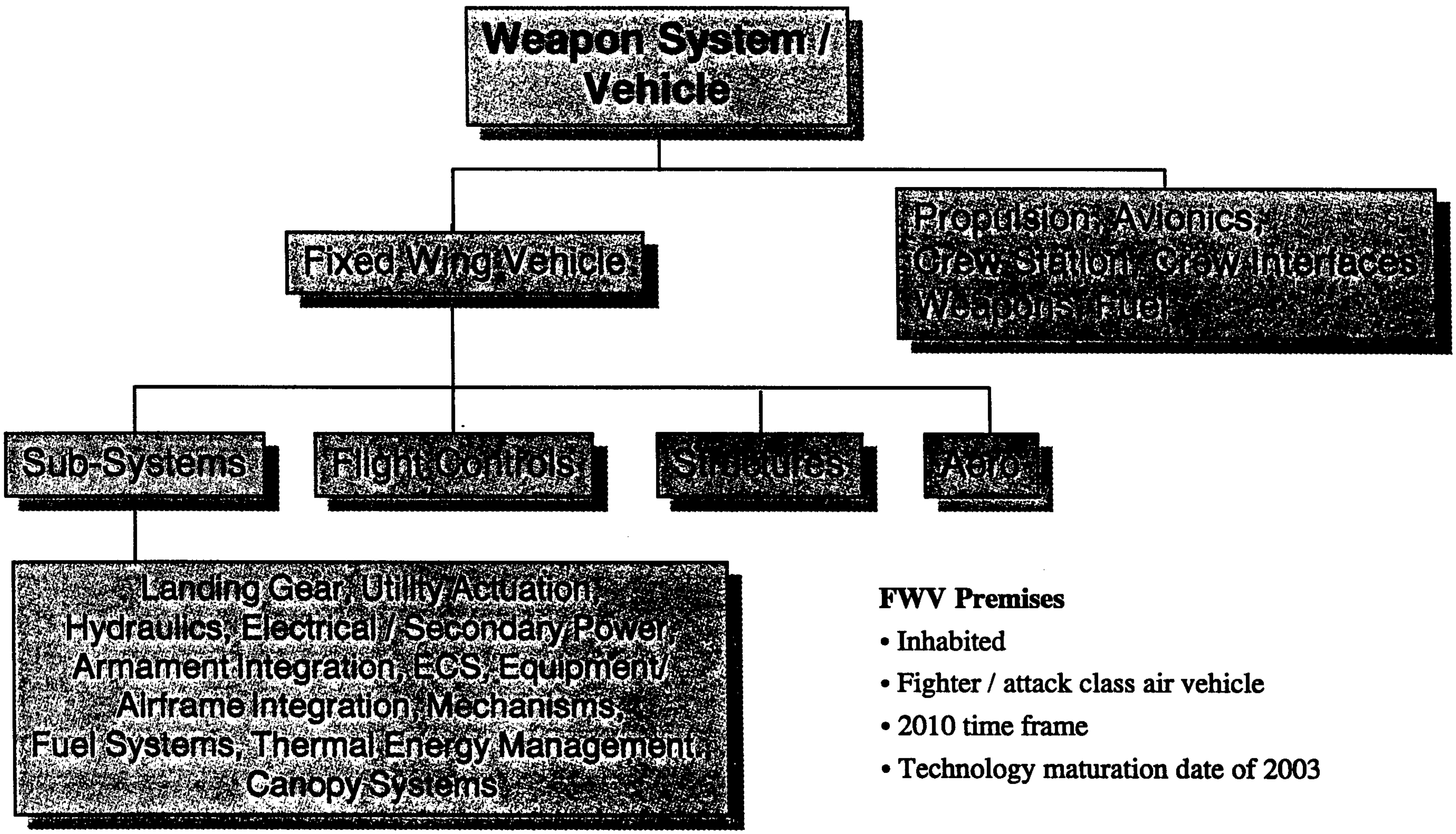
- Process Overview
- **Results**
- Conclusions

FWV Weapon System Definition is an Important Cornerstone

Charted here is a block diagram representation of the definition of a FWV. Also shown are the classic air vehicle / weapon system components not expressly considered part of the FWV program (propulsion, avionics, crew station, etc....).

Also documented here are the driving premises around which the FWV program assessments have been made. Specifically, an inhabited, fighter / attack class air vehicle with an Initial Operational Capability (IOC) in the 2010 time frame. 2010 would suggest (demand) a technology maturation date of 2003.

FWV Weapon System Definition is an Important Cornerstone



FWV Premises

- Inhabited
- Fighter / attack class air vehicle
- 2010 time frame
- Technology maturation date of 2003

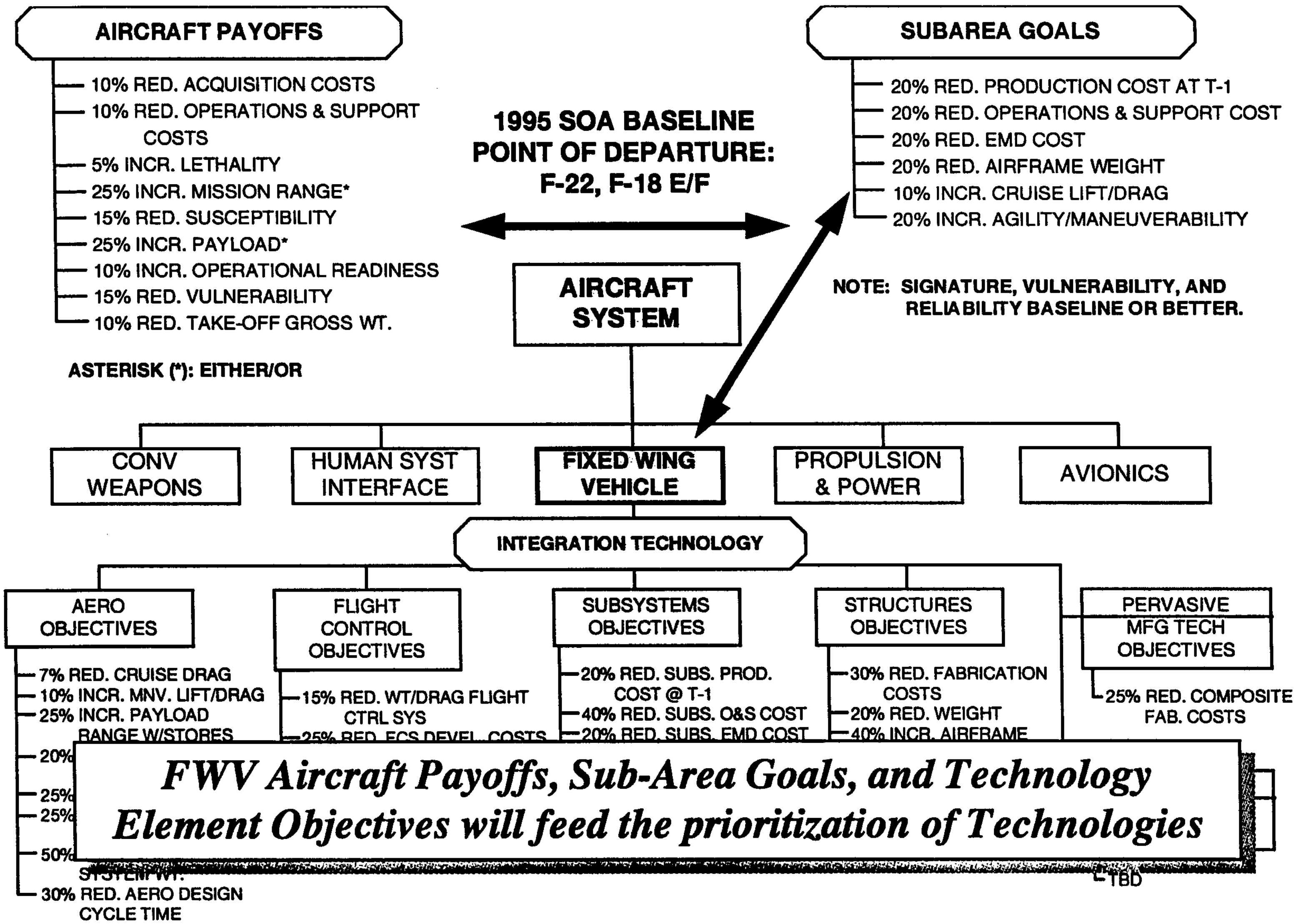
Customer's "Razor Chart" Formed the Basis for FWV QFD

This version of the customer "razor chart" was used to construct the FWV QFD application.

The Aircraft Payoffs were the starting point, and the process linked these to the Sub-Area Goals to the TEOs , through a series of two matrices. A unique feature of the FWV QFD is that the customer's hierarchy was immediately compatible with the QFD process.

No manipulation was done on any of the customer Aircraft Payoffs, Sub-Area Goals or TEOs. A definition, however, was drafted for each and reviewed with the customer for accuracy during the 4-5 Aug 97 customer / Boeing STL meeting.

Customer's "Razor Chart" Formed the Basis for FWV QFD



QFD Links FWV Aircraft Payoffs to Technologies

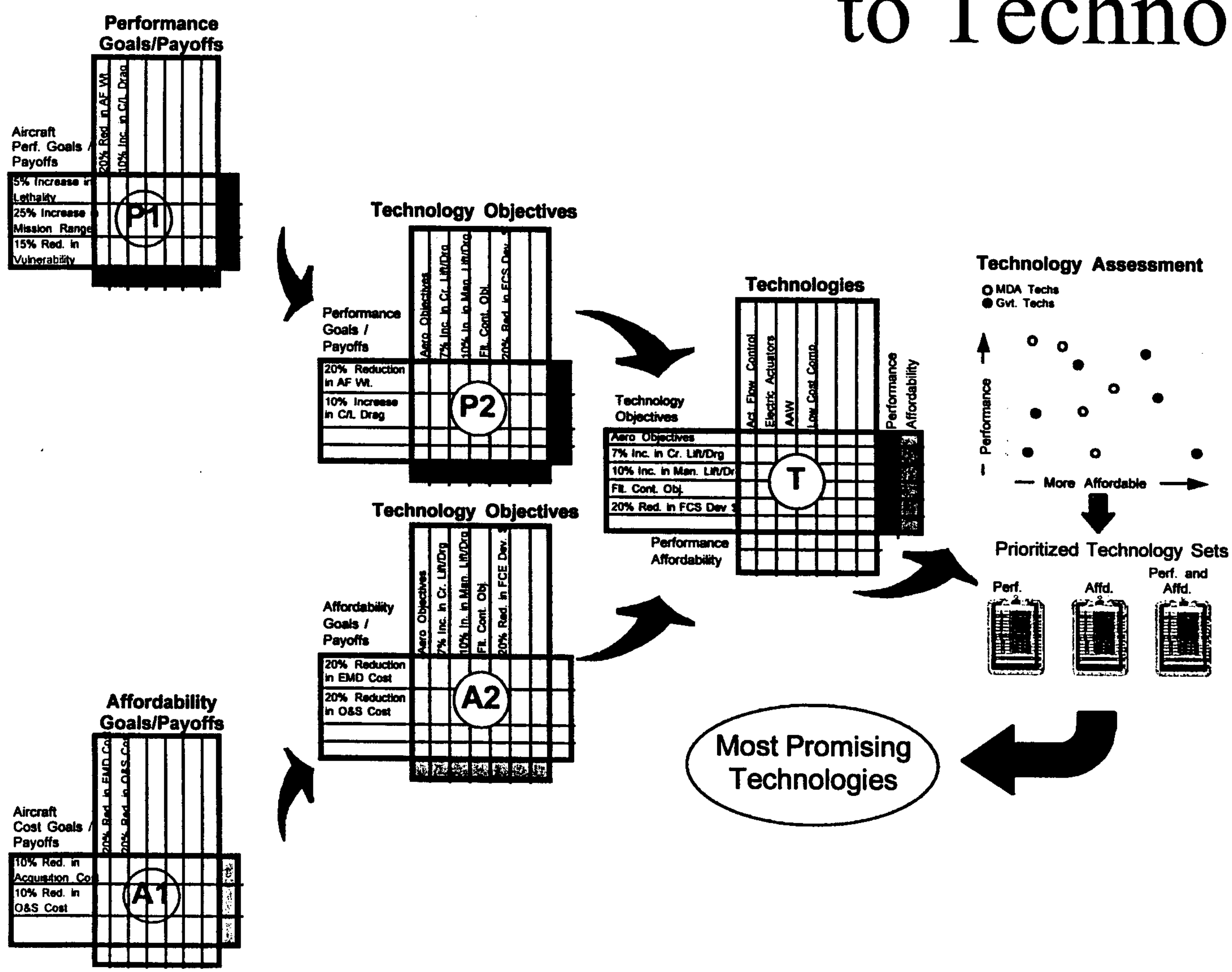
This graphic depicts the overall FWV QFD architecture.

Note there are two tracks leading to the "T" matrix where technologies are to be scored against TEOs. The "P" track is designed to document the performance issues and the "A" track the affordability or cost issues.

All four matrices P1, P2, A1 and A2 were completed during the 4-5 Aug 97 customer / Boeing STL meeting.

The "T" matrix was scored independently by both the respective customer and Boeing STL technology subject matter experts, then reviewed in totality by both the customer and Boeing STL FWV program management and the technology leaders during a facilitated 20-21 Aug 97 customer / Boeing STL meeting.

QFD Links FWV Aircraft Payoffs to Technologies



Weighing Aircraft Payoffs

The first step in executing the QFD process is to identify the opening set of objectives. For the FWV application the 1st set of objectives were the FWV Aircraft Payoffs. With the definitions for each Aircraft Payoff agreed to by the customer the second QFD step could be entertained, assigning a priority to each Aircraft Payoff.

One approach would be to treat each Aircraft Payoff equally. When this proposition was offered to the customer at the 4-5 Aug 97 customer / Boeing STL meeting you can see by the array of scores that no one valued the Aircraft Payoffs equally.

Six voices were solicited privately, then presented publicly for the remainder of the group to see. What quickly became obvious was the overwhelming dominance the two affordabilty payoffs enjoyed compared to the remaining seven performance payoffs. The group easily agreed that the two affordability payoffs should consume 50 of the 100 available points. Building consensus on the remaining seven performance payoffs required more time but essentially the seven were broken into two groups. Lethality, Range, Susceptibly and Readiness were valued roughly twice as much as Payload, Vulnerability and Take Off Gross Weight.

It is significant that neither the FWV Sub-Area Goals or the TEOs address the mission related Aircraft Payoffs of; Lethality, Susceptibly, Operational Readiness or Vulnerability. These Aircraft Payoffs had very little influence on the eventual prioritization of FWV technologies.

Weighing Aircraft Payoffs

Aircraft Payoffs	Voice # 1	Voice # 2	Voice # 3	Voice # 4	Voice # 5	Voice # 6	Consensus
Acquisition Cost	35	15	20	35	25	19	**30**
O/S Cost	20	15	20	15	25	29	**20**
Lethality	4	7	10	10	5	9	**8**
Range	20	16	5	5	10	4	**10**
Susceptability	4	10	10	10	10	4	**9**
Payload	5	6	10	5	5	4	**5**
Readiness	5	7	10	10	10	14	**9**
Vulnerability	2	10	5	5	5	14	**4**
TO[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

question asked:
"If given $100.- How would you invest to satisfy FWV Aircraft Payoffs?"

Overall rationale for consensus weighting:
Seven Performance Payoffs - 50%
Two Affordability (cost savings) Payoffs - 50%

Matrix P1/A1

Because of the small number of Aircraft Payoffs, both the performance and affordability tracks were combined into a single matrix. Thus this first FWV matrix is now called P1/A1 because it contains both the performance and affordability Aircraft Payoffs. Across the top of the matrix again note that both sets of Sub-Areas Goals are included, the performance and affordability Sub-Area Goals. The same array of weights that were agreed to represent the relative priority of the Aircraft Payoffs is documented on the right side of the matrix.

Occasionally you will notice a small triangle in the upper right hand corner of certain cells. These triangles represent areas where complete agreement was not reached, and a note was taken to document the nature of the discord.

When the matrix math was completed, and the raw scores scaled to 100, the resulting bar graph at the bottom of the chart shows that the affordability Sub-Area Goals represent 59% of the emphasis in satisfying the Aircraft Payoffs. The remaining 41% are accorded to performance Sub-Area Goals.

Finally it is interesting to note that the affordability Sub-Area Goals almost uniquely support the affordability Aircraft Payoffs and that the opposite is true for the performance Sub-Area Goals. The performance Sub-Area Goals support a broad spectrum of the FWV Aircraft Payoffs.

Matrix P1/A1

Sub-Area Goals satisfying Aircraft Payoffs

Aircraft Payoffs vs. Subarea Goals		
Strong	●	9.0
Moderate	○	3.0
Weak	△	1.0

Aircraft Payoffs	Subarea Goals	20% Red. in Prod. Cost at T-1	20% Reduction in O&S Cost	20% Reduction in EMD Cost	20% Red. in Airframe Weight	10% Increase in Cruise L/D	20% Inc. in Agility / Man.	Aircraft Payoff Priorities
10% Reduction in Acquisition Costs		●		●	○			30
10% Reduction in O&S Costs			●		△	△		20
5% Increase in Lethality					△		●	8
25% Increase in Mission Range					○	●	△	10
15% Reduction in Susceptibility							○	9
25% Increase in Payload					●	○		5
10% Increase in Operational Readiness			○		△			9
15% Reduction in Vulnerability					△		○	4
10% Reduction in Gross Take-Off Weight					●	○		5
Raw Scores	0	270	207	270	251	140	121	
Raw Scores Scaled to 100 percent	0	21	16	21	20	11	10	

Max = 25.0

Raw Scores Scaled to 100 percent

Min = 0.0

Sub-Area Goals:
59% Affordability
41% Performance

Matrix P2/A2

Here the Technology Element Objectives (TEO) are being prioritized with respect to the Sub-Area Goals. The exact output results of Matrix P1/A1 are flowed into Matrix P2/A2. Again the affordability and performance tracks have been combined. Note that the exact array of Sub-Area Goal's weights, documented on the right side of this matrix, are those produced by Matrix A1/P1.

If the affordability TEOs output scores are summed, they represent 53% of the ability to satisfy the Sub-Area Goals. The 11 affordability TEOs include any TEO with the word 'cost' and two others; '30% Reduction in Aero Design Cycle Time' and '70% Reduction in Control Related Accidents'. This is significant because the original split on the Aircraft Payoffs between affordability and performance was set at 50% / 50%.. Without any conscious effort, the emphasis between affordability and performance is being preserved through the FWV QFD flow.

30% of the Sub-Area Goal satisfaction can be attributed to the Aero TEOs, 24% to the Flight Control TEOs, 19% to the Sub-system TEOs and 29% to the Structures TEOs. The conclusion could be that the Flight Control and Sub-system TEOs do not make as significant a contribution as the other two areas until you notice that the #1 ranked TEO is a Flight Control TEO, '15% Reduction in Weight/Drag of Flight Control Systems'. The appropriate conclusion is to not over focus on the traditional groupings of Aero, Flight Controls, Sub-systems or Structures.

Matrix P2/A2

Strong	●	9.0
Moderate	○	3.0
Weak	△	1.0

Technology Element Objectives (TEOs) satisfying Sub-Area Goals

TEOs:
53% Affordability
47% Performance

Subarea Goals	Aero Objectives	7% Reduction in Cruise Drag	10% Increase in Maneuver L/D	25% Increase in Payload / Range with Stores	20% Increase in Landing Approach Lift Coefficient	25% Reduction in Nozzle Weight	25% Reduction in Nozzle Acquisition Cost	50% Reduction in Duct Inlet Weight	30% Reduction in Aero Design Cycle Time	Flight Control Objectives	15% Reduction in Weight/Drag Flight Control Systems	25% Reduction in FCS Development Cost	20% Increase in Agility	70% Reduction in Control Related A	30% Reduction in FCS O&S Costs	Sub-system Objectives	20% Reduction in Sub-system Prod	40% Reduction in Sub-system O&S	20% Reduction Sub-system EMD C	20% Reduction in Sub-system Weig	Structures Objectives	30% Reduction in Structural Manufa	20% Reduction in Structural Operations and Support Cost	25% Reduction in Structural Design Cycle Cost	20% Reduction in Structural Weight	Raw Scores	Raw Scores Scaled to 100 percent	Max = 25.0 Raw Scores Scaled to 100 percent Min = 0.0
																										0	0.00	
20% Reduction in Production Cost at T-1		△	△		△		○	○			○						●			△		●	△	△	○	270	21.45	
20% Reduction in O&S Cost		△	△	△	△	△		△			△			●	●			●		△		△	●		△	207	16.44	
20% Reduction in EMD Cost							○	△	●			●		△					●	△		●	△	●	△	270	21.45	
20% Reduction in Airframe Weight		△	△		△	●		○			●									●			△	△	●	251	19.94	
10% Increase in Cruise L/D		●	○	●							●									△				△	○	140	11.12	
20% Increase in Agility / Maneuverability		△	●		△	△					△		●							△				△	△	121	9.61	
Raw Scores	0	166	180	115	67	206	126	160	189	0	368	189	90	165	144	0	189	144	189	259	0	394	206	251	323			
Raw Scores Scaled to 100 percent	0.00	4.03	4.37	2.79	1.63	5.00	3.06	3.88	4.59	0.00	8.93	4.59	2.18	4.00	3.50	0.00	4.59	3.50	4.59	6.29	0.00	9.56	5.00	6.09	7.84			
Max = 10.0 Raw Scores Scaled to 100 percent Min = 0.0																												

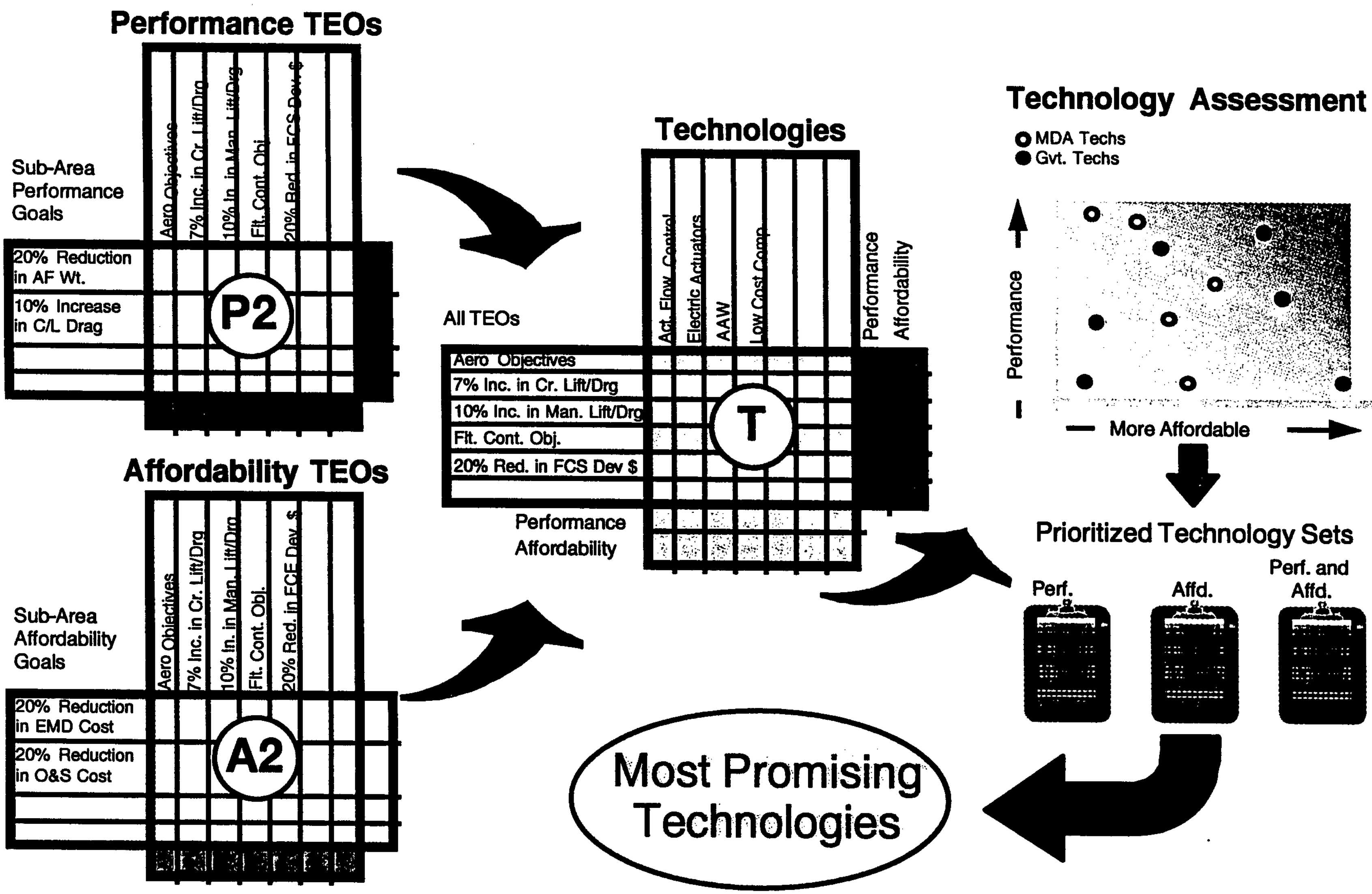
QFD was the Basis for the Selection of the Most Promising Technologies

Here's a blow-up of the "T" matrix, and possible paths to pursue once this matrix is complete.

A plot of technology performance satisfying FWV goals verses technology affordability was proposed as a logical output from which a cut at the most promising technologies to incorporate on the FWV program could be made. Three perspectives were also proposed, 1) an affordability only, 2) a performance only, and 3) a combined affordability and performance perspective.

A fourth perspective was also evaluated - the ratio of the combined affordability and performance divided by the investment cost for each technology to reach Technology Readiness Level 6 by 2003.

QFD was the Basis for the Selection of the Most Promising Technologies



Matrix T

Matrix T is the only FWV QFD matrix that contained a negotiable axis. In all the previous matrices the axis elements were identified in the customer's "razor chart" and were essentially, non-negotiable. This is a unique feature of the FWV QFD. Almost always the most time consuming portion of a QFD application is the architecture set-up and identifying and defining each axis element.

Here 44 FWV technologies were evaluated for their potential ability to satisfy the TEOs. The technologies, like the TEOs, were grouped in four classic areas, Aerodynamics, Flight Controls, Sub-systems and Structures. Overall Aero and Structures technologies appear to best satisfy the TEOs. Note that the evaluators could rate a technology as negatively impacting a TEO, and that negative assessments occurred in number of cells. Also note that the majority of the scoring, and especially the "STRONG" scores, occurred in the intersections of a technology area with the respective set of TEOs. Sub-system technologies interacting with Sub-system TEOs is a good example. This is not true with the Aero technologies, frequently Aero technologies were assessed to contribute to other TEOs.

Not displayed, but of significance, is the fact that the 44 technology's ability to satisfy TEOs were evenly split between the affordability and performance TEOs. 50% of the output emphasis of this matrix satisfies affordability TEOs and 50% satisfies performance TEOs. Thus, throughout the entire FWV QFD flow, there was consistency in the original, balanced affordability / performance emphasis.

Matrix T

Aero / Structures / Flight Controls / Sub-Systems Technologies satisfying TEOs

Strong	●	9.0
Moderate	O	3.0
Weak	Δ	1.0
Weak Negative	∇	-1.0
Moderate Negative	⊚	-3.0

Aerodynamics

	Exhaust system (Fluidic Vectoring Nozzle)	Advanced wing planforms	Integrated external weapons carriage	Compact inlet system/inlet-aerostructure integration	Flow control - MEMS	Active flow control (other than MEMS)	Tailless	Integrated Internal Carriage	LFC for low aspect ratio wing	Expandable fuel cell	Aero Synthesis Tools	Wind Tunnel Test Productivity
Aero Objectives												
7% Reduction in Cruise Drag	O	●		O	O	●	●		O	●		
10% Increase in Maneuver L/D	O	●		Δ	Δ	O	O	O		Δ		
25% Increase in Payload / Range with Stores	O	O	●	O	Δ	O	O	O	O	●		
20% Increase in Landing Approach Lift Coefficient		O	Δ	Δ	Δ	O	Δ		Δ			
25% Reduction in Nozzle Weight	●				O	●						
25% Reduction in Nozzle Acquisition Cost	●				Δ	●						
50% Reduction in Duct Inlet Weight				●	O	●						
30% Reduction in Aero Design Cycle Time		O	Δ	Δ	Δ	Δ					●	●
Flight Control Objectives												
15% Reduction in Weight/Drag Flight Control Systems	Δ	O			O	O	●					
25% Reduction in FCS Development Cost							Δ					
20% Increase in Agility	O	O	Δ		Δ	Δ	Δ	O		O		
70% Reduction in Control Related Accidents					Δ							
30% Reduction in FCS O&S Costs						Δ	Δ					
Sub-system Objectives												
20% Reduction in Sub-system Production Cost at T-1	Δ			Δ				∇		∇		
40% Reduction in Sub-system O&S Costs	Δ	∇					Δ	⊚		∇		
20% Reduction Sub-system EMD Cost	Δ							∇		∇		
20% Reduction in Sub-system Weight	Δ	∇						∇		∇		
Structures Objectives												
30% Reduction in Structural Manufacturing Cost		O		O			O					
20% Reduction in Structural Operations and Support Co				Δ			Δ					
25% Reduction in Structural Design Cycle Cost							O					O
20% Reduction in Structural Weight		O		O			O					
Raw TI	140.53	178.37	33.52	127.79	88.16	207.16	229.00	2.09	22.09	53.35	41.29	59.56
Percent TI	4.10	5.20	0.98	3.73	2.57	6.04	6.68	0.06	0.64	1.56	1.20	1.74

Flight Controls

	Forebody Vortex Flow Control	Multivariable Reconfigurable Control	Flight Control Power-By-Wire/Electric Actuatio	Fly-By-Light Closed-Loop Control	Performance Seeking Aircraft Control	Multi-Axis Thrust Vector Control	COTS Hardware & Software	Automated Closed Loop Coupling	Genetic Algorithm Flight Control Laws	Online Diagnostics for Two Level Maintenanc	Flight Control Rapid Prototyping Process	Fiber Optic Gyro Inertial Measurement Sens	Intelligent Damage Adaptive Control System	Laser Optical Air Data System
Aero Objectives														
7% Reduction in Cruise Drag	Δ				O				Δ		Δ		Δ	
10% Increase in Maneuver L/D	O	O			Δ				Δ		Δ		Δ	
25% Increase in Payload / Range with Stores	Δ	O			O				Δ		Δ		Δ	
20% Increase in Landing Approach Lift Coefficient	Δ	O			Δ	O			Δ		Δ		Δ	
25% Reduction in Nozzle Weight		O												
25% Reduction in Nozzle Acquisition Cost														
50% Reduction in Duct Inlet Weight		Δ												
30% Reduction in Aero Design Cycle Time		Δ												
Flight Control Objectives														
15% Reduction in Weight/Drag Flight Control Systems	O	O	Δ		O	Δ	O	Δ	Δ		Δ		Δ	
25% Reduction in FCS Development Cost		Δ		Δ			O		O		●	Δ		Δ
20% Increase in Agility	O	O			Δ	●		O	Δ		Δ	O	Δ	Δ
70% Reduction in Control Related Accidents	Δ	●	Δ	Δ	Δ	O	O	●	O	Δ	Δ	Δ	●	Δ
30% Reduction in FCS O&S Costs		O	O	O	O	Δ	●	Δ	Δ	●	O	Δ	Δ	O
Sub-system Objectives														
20% Reduction in Sub-system Production Cost at T-1		Δ				∇								
40% Reduction in Sub-system O&S Costs		Δ	O			⊚		Δ					Δ	
20% Reduction Sub-system EMD Cost		Δ				∇								
20% Reduction in Sub-system Weight		Δ	Δ			∇								
Structures Objectives														
30% Reduction in Structural Manufacturing Cost														
20% Reduction in Structural Operations and Support Co		Δ						Δ					Δ	
25% Reduction in Structural Design Cycle Cost														
20% Reduction in Structural Weight														
Raw TI	58.91	158.25	40.19	19.08	69.93	23.03	84.03	63.52	53.20	35.46	79.71	18.64	71.97	21.26
Percent TI	1.72	4.62	1.17	0.56	2.04	0.67	2.45	1.85	1.55	1.03	2.32	0.54	2.10	0.62

Subsystems

	Subsystems Power-by-wire/electric actuation	Integrated VMS	Advanced Landing Gear	Extended tire life	Energy Management System	Aircraft Survivability	Advanced canopy technology	Subsystems Virtual Design
Aero Objectives								
7% Reduction in Cruise Drag					O			
10% Increase in Maneuver L/D								
25% Increase in Payload / Range with Stores								
20% Increase in Landing Approach Lift Coefficient								
25% Reduction in Nozzle Weight								
25% Reduction in Nozzle Acquisition Cost								
50% Reduction in Duct Inlet Weight								
30% Reduction in Aero Design Cycle Time								
Flight Control Objectives								
15% Reduction in Weight/Drag Flight Control Systems								
25% Reduction in FCS Development Cost								
20% Increase in Agility								
70% Reduction in Control Related Accidents								
30% Reduction in FCS O&S Costs						Δ		
Sub-system Objectives								
20% Reduction in Sub-system Production Cost at T-1		Δ			Δ	Δ	●	
40% Reduction in Sub-system O&S Costs	O	●	O	●	O	●	●	
20% Reduction Sub-system EMD Cost		O						●
20% Reduction in Sub-system Weight	O	Δ	O		●	Δ	Δ	
Structures Objectives								
30% Reduction in Structural Manufacturing Cost								
20% Reduction in Structural Operations and Support Co		O	Δ			Δ		
25% Reduction in Structural Design Cycle Cost								
20% Reduction in Structural Weight			Δ		Δ			
Raw TI	29.34	71.09	42.18	31.46	91.58	50.83	79.03	41.29
Percent TI	0.86	2.07	1.23	0.92	2.67	1.48	2.30	1.20

Structures

	Integrally stiffened composite structures to minimize mechanical fastening	Unitized metallic substructures; welded, low cost, light weight, durable	Inspection/NDI systems for advanced structural concepts	Repair technology for advanced structural concepts	Survivable Structures	Exhaust Wash Structures	Conformal load-bearing antenna structures	Active aeroelastic wing	Active load/buffet alleviation for flight surfaces	Design, Manufacturing, and Producibility Simulation (DMAPS)	Raw Scores	Raw Scores Scaled to 100 percent
Aero Objectives												
7% Reduction in Cruise Drag								O			166	4.03
10% Increase in Maneuver L/D								O			180	4.37
25% Increase in Payload / Range with Stores								●			115	2.79
20% Increase in Landing Approach Lift Coefficient								O			67	1.63
25% Reduction in Nozzle Weight		Δ				●					206	5.00
25% Reduction in Nozzle Acquisition Cost		Δ				O					126	3.06
50% Reduction in Duct Inlet Weight	Δ										160	3.88
30% Reduction in Aero Design Cycle Time											189	4.59
Flight Control Objectives												
15% Reduction in Weight/Drag Flight Control Systems								O			368	8.93
25% Reduction in FCS Development Cost											189	4.59
20% Increase in Agility	Δ	Δ						O			90	2.18
70% Reduction in Control Related Accidents											165	4.00
30% Reduction in FCS O&S Costs											144	3.50
Sub-system Objectives												
20% Reduction in Sub-system Production Cost at T-1						∇					189	4.59
40% Reduction in Sub-system O&S Costs					●						144	3.50
20% Reduction Sub-system EMD Cost											189	4.59
20% Reduction in Sub-system Weight					∇						259	6.29
Structures Objectives												
30% Reduction in Structural Manufacturing Cost	●	●	O		Δ	Δ	Δ	O		●	394	9.56
20% Reduction in Structural Operations and Support Co			●	●	●	O	O		O	Δ	206	5.00
25% Reduction in Structural Design Cycle Cost	O	O								●	251	6.09
20% Reduction in Structural Weight	●	●				O	Δ	O	Δ	Δ	323	7.84
Raw TI	180.97	185.15	73.69	45.00	79.73	97.67	32.40	140.75	22.84	153.74		
Percent TI	5.28	5.40	2.15	1.31	2.33	2.85	0.95	4.10	0.67	4.48		

Max = 10.0
Raw Scores Scaled to 100 percent
Min = 0.0

Max = 8.0
Percent TI
Min = 0.0

Matrix T Results Build to Bottom Line

This list represents the sequential series of output graphs from the FWV QFD matrices that build to the bottom line conclusion.

A short discussion will follow on each chart, however, those shaded in light red are probably the more significant.

Three perspectives were explored in charting the FWV QFD data, an affordability only perspective, a performance only perspective and a third perspective where affordability and performance were equally valued.

A fourth perspective was computed where the combined affordability and performance QFD scores (the 3rd perspective discussed above) was divided by the investment cost to reach Technology Readiness Level (TRL) 6 in 2003.

The third and fourth perspectives were ultimately compared to arrive at the bottom line conclusion of the 14 technologies which appear to offer the most benefit for the investment.

Matrix T Results Build to Bottom Line

- Aero / Flight Controls / Sub-Systems / Structures Technologies satisfying **only** Affordability TEOs
- Aero / Flight Controls / Sub-Systems / Structures Technologies satisfying **only** Performance TEOs
- **All** Technologies satisfying **only** Affordability TEOs
- **All** Technologies satisfying **only** Performance TEOs
- **All** Technologies satisfying **combination** of Performance + Affordability TEOs
- **Investment** ($M) to reach Technology Readiness Level (TRL) 6
- **Map** of Technologies satisfying **only** Affordability TEOs vs Investment ($M) to reach TRL 6
- **Map** of Technologies satisfying **only** Performance TEOs vs Investment ($M) to reach TRL 6
- **Map** of All Technologies satisfying **combination** of Performance + Affordability TEOs vs Investment ($M) to reach TRL 6
- **Ratio** of Technology QFD score satisfying **combination** of Performance + Affordability TEOs divided by Investment ($M) to reach TRL 6
- **Cumulative stack** of Investment ($M) to reach TRL 6 and QFD score satisfying **combination** of Performance + Affordability TEOs

Bottom line -
Which technologies offer the most benefit for the investment?

Aero Technologies - Affordability Perspective

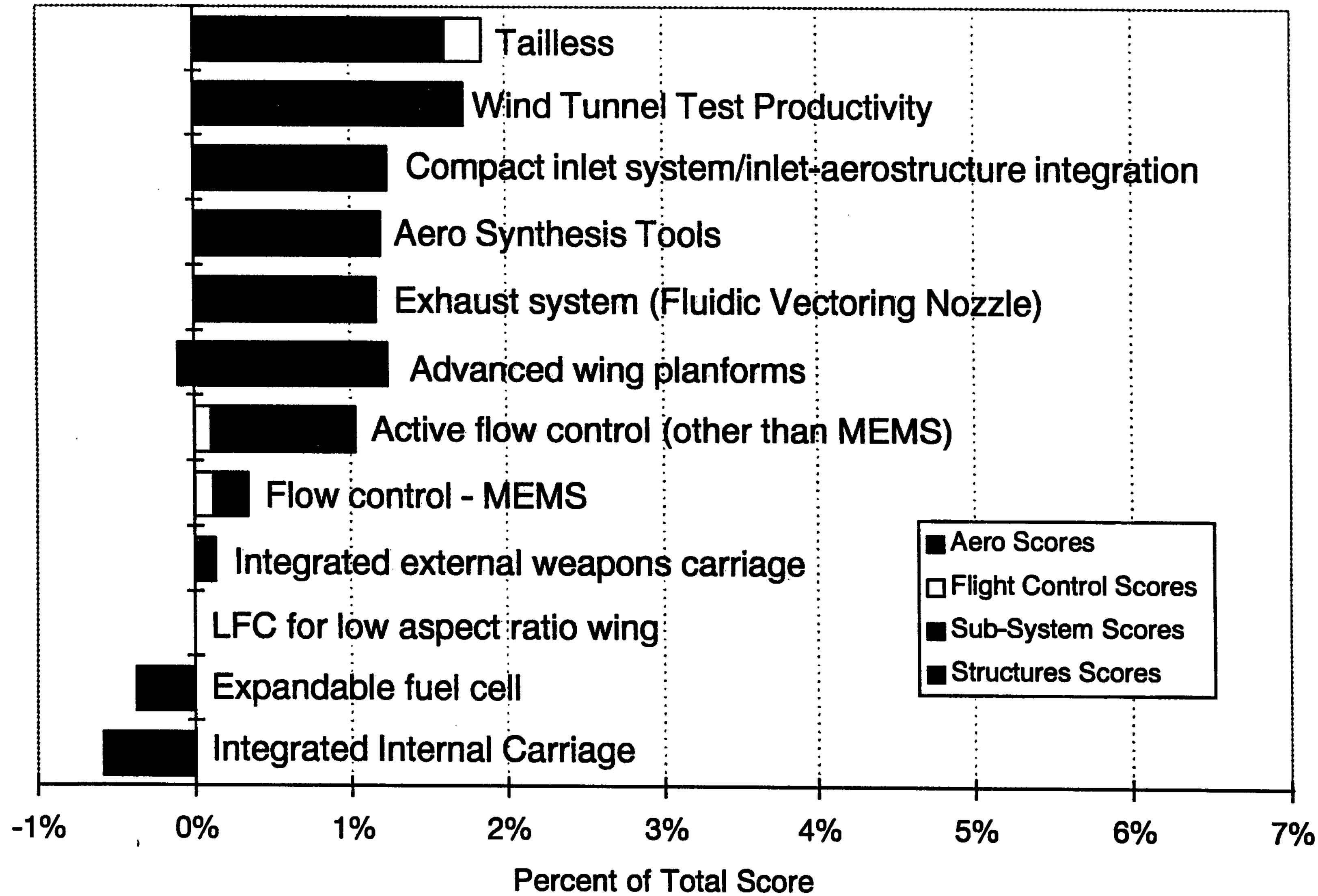
This plot charts the relative ability of just the Aero technologies to satisfy just the 11 affordability TEOs. It also shows the relative proportion of which set of TEOs the respective technology is satisfying.

Tailless was assessed to have the best potential satisfying the affordability TEOs. Furthermore, Tailless strongly satisfied Structures affordability TEOs, contributed some to Flight Control affordabilty TEOs and Sub-system affordabiltiy TEOs, but did not satisfy a single Aero affordabilty TEO. This can be verified by reviewing the raw data documented in Matrix T.

To properly interpret the impact of these charts recall, that the total of all the 44 technologies scores satisfying just the affordabilty TEOs is almost exactly 50%.. Also recall, the total of all the 44 technologies scores satisfying just performance TEOs is almost exactly 50%.. Thus one can interpret these relative percent scores based on a overall total of 100%.. For example, the Tailless technology's affordability satisfaction was nearly 2% of the TEOs and we have not yet accounted for Tailless technology's ability to satisfy performance TEOs. Undoubtedly the overall ability of Tailless technology to satisfy the complete set of TEOs will increase when the performance TEOs are examined.

Finally, note that some aero technologies inhibited the satisfaction of affordability TEOs, such as; 'Expandable Fuel Cell' and 'Integrated Internal Carriage'.

Aero Technologies - Affordability Perspective

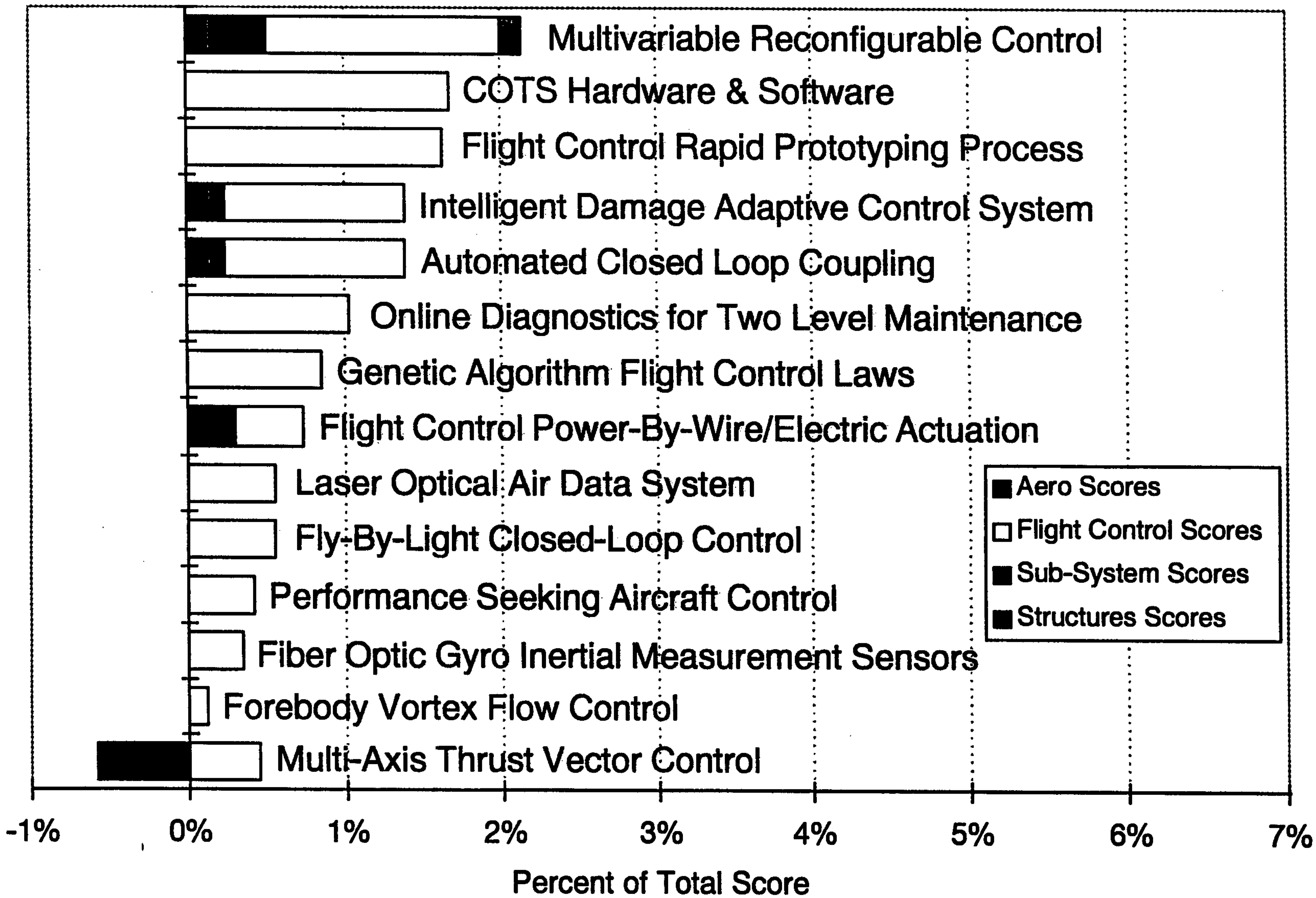


Flight Control Technologies - Affordability Perspective

When the remainder of the technology areas are examined satisfying just affordability TEOs note that each technology area only principally interacted with its respective set of TEOs.

The overwhelming majority of Flight Control technology's ability to satisfy affordability TEOs was only assessed in the Flight Control TEOs, i.e., the graph is mostly yellow.

Flight Control Technologies - Affordability Perspective

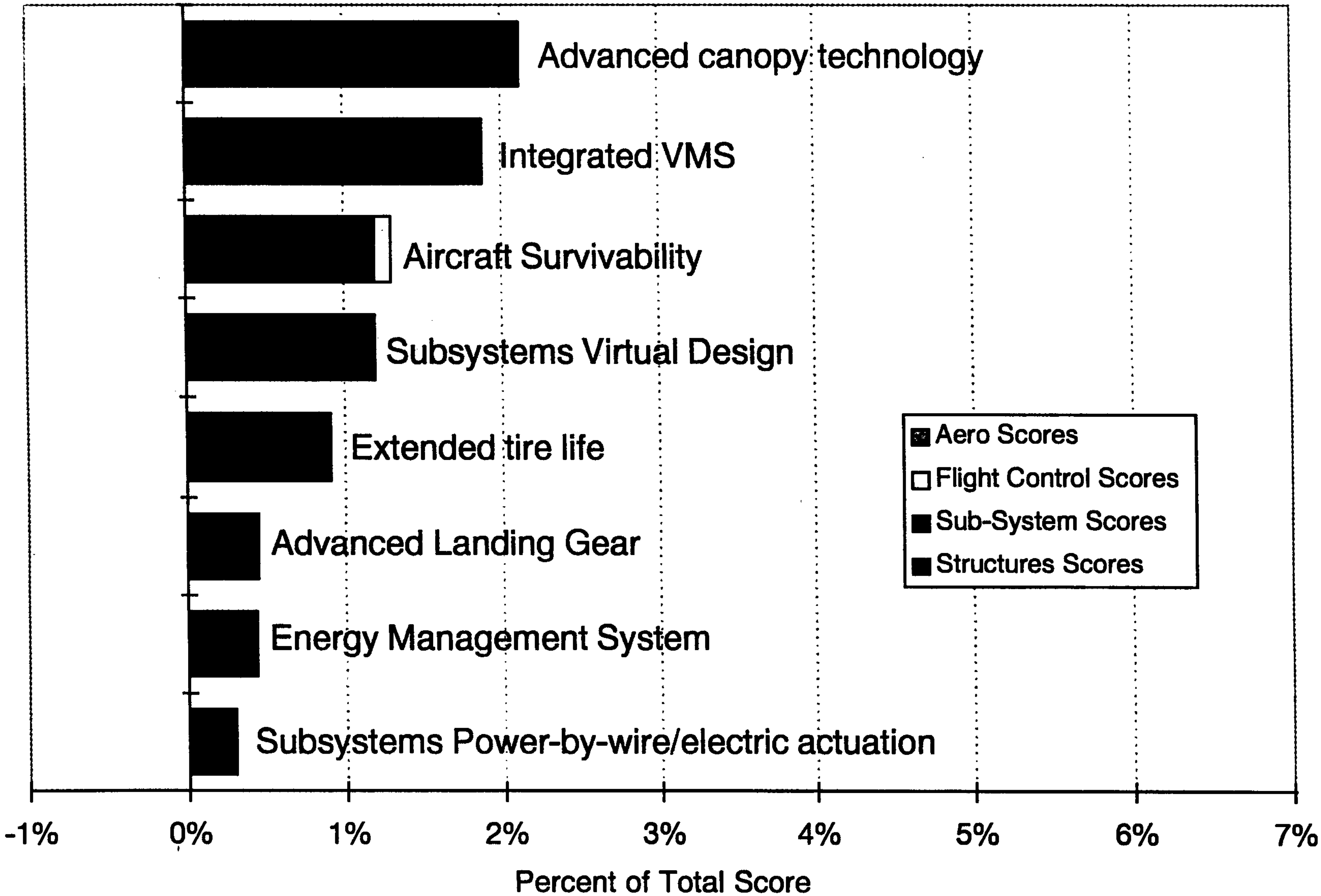


Sub-Systems Technologies - Affordability Perspective

Sub-systems technologies almost uniquely satisfied Sub-system affordability TEOs, i.e., this graph is almost all blue! Sub-system technologies do not satisfy Aero, Flight Control or Structures TEOs.

Note that so far, in Aero, Flight Controls and Sub-systems the leading technology is gathering about 2% of the emphasis.

Sub-Systems Technologies - Affordability Perspective



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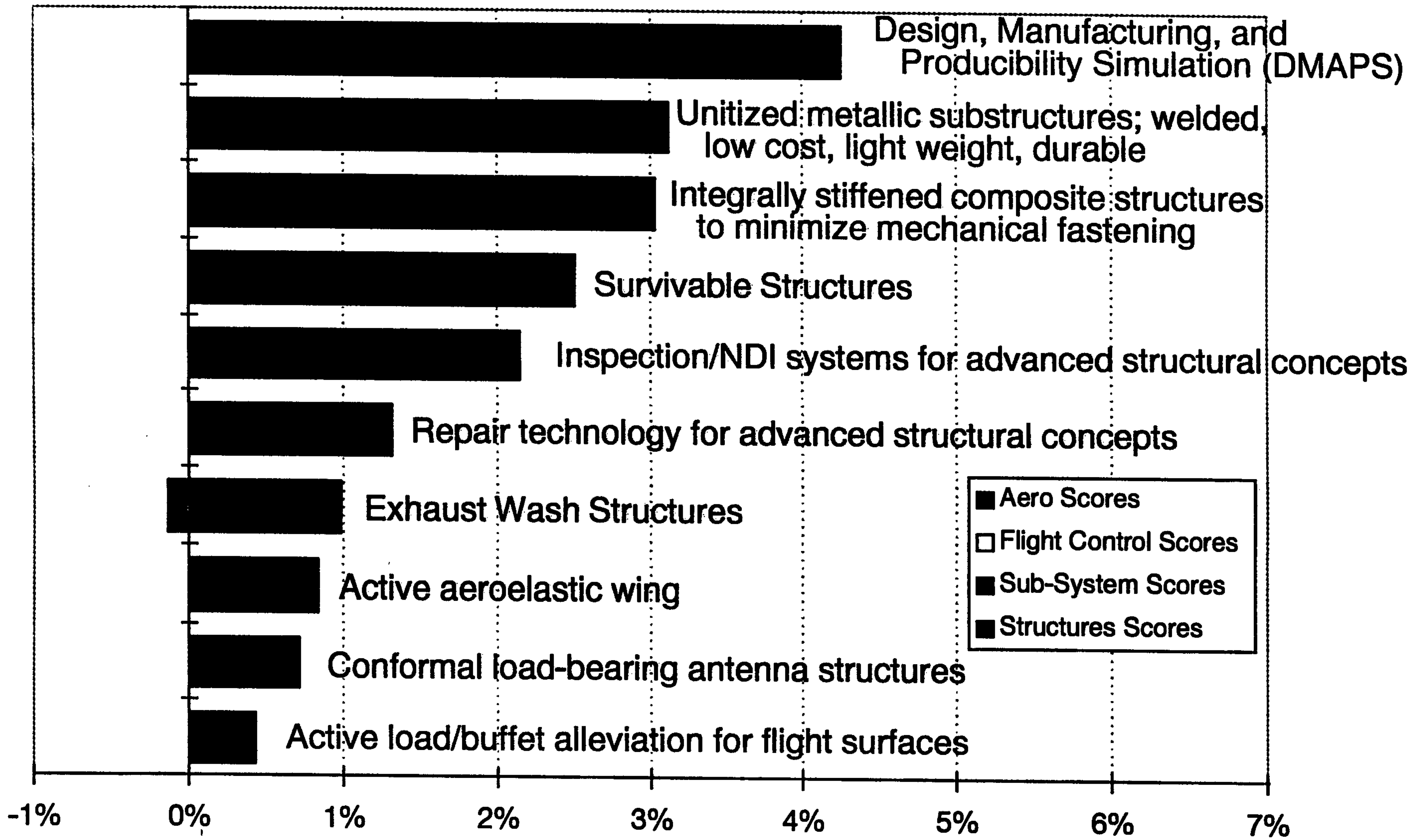
Structures Technologies - Affordability Perspective

Like, Sub-systems technologies, Structures technologies almost uniquely satisfied Structures affordability TEOs, i.e., this graph is almost all green!

But now note that the leading Structures technology, 'DMAPS' is gathering over 4% of the overall output emphasis and remember this is just 'DMAPS' ability to satisfy the affordability TEOs.

Structures Technologies - Affordability Perspective



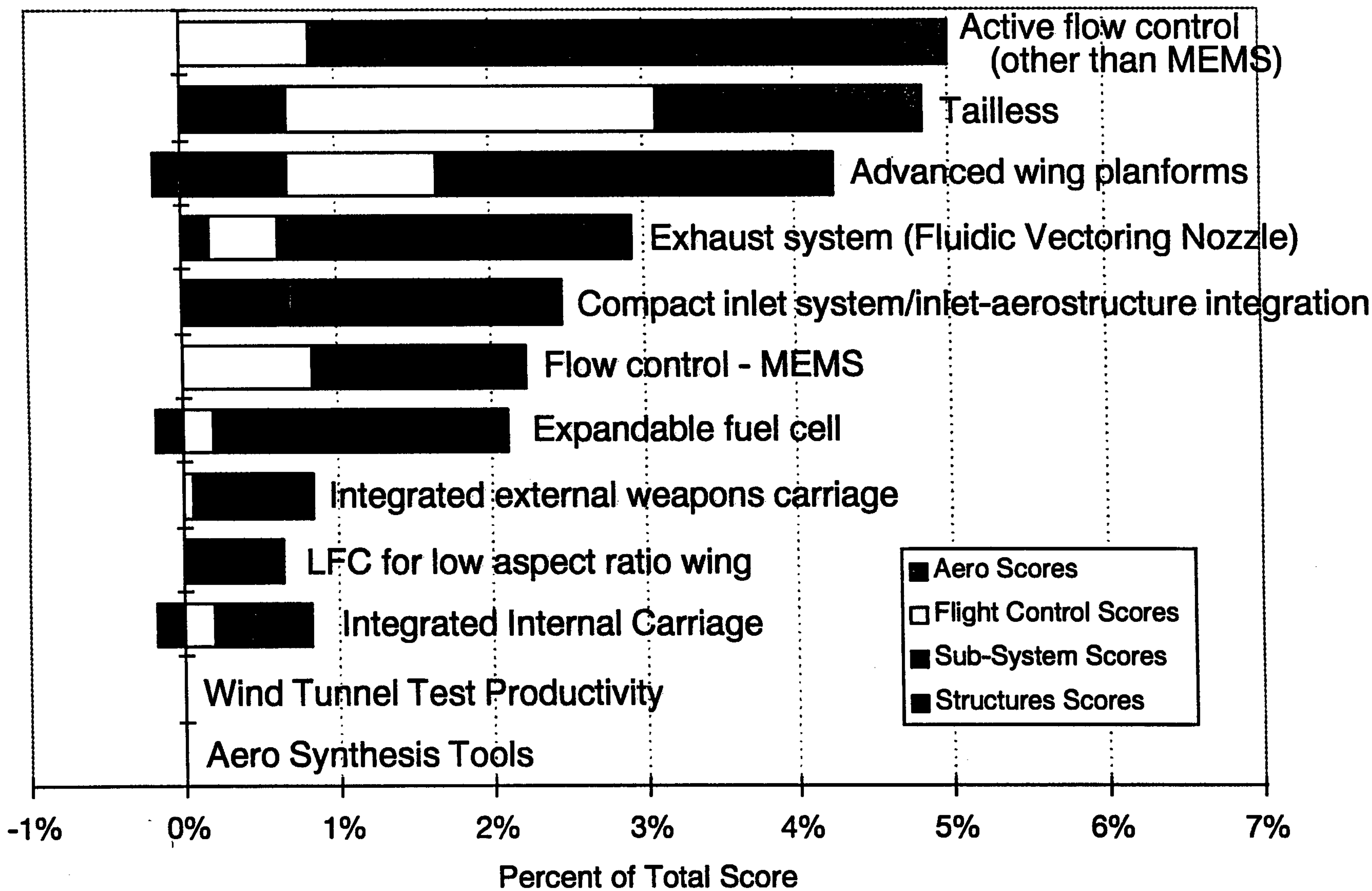
Aero Technologies - Performance Perspective

Now we shift gears and instead of looking at just the 11 affordability TEOs, in the next four charts we will examine the four sets of technology's ability to satisfy just the 10 performance TEOs.

Here two significant thing are shown. 1) the leading Aero technology, 'Tailless' is gathering 5% of the output emphasis and 2) the Aero technologies, in general, are satisfying mostly Aero TEOs.

You could also conclude that due to the simple 'surface area' of the bars on this chart the Aero technologies are roughly twice as effective as satisfying the performance TEOs as they are satisfying affordability TEOs. Compare the 'surface areas' between the two Aero technology graphs and notice that this graph possesses about twice as much.

Aero Technologies - Performance Perspective

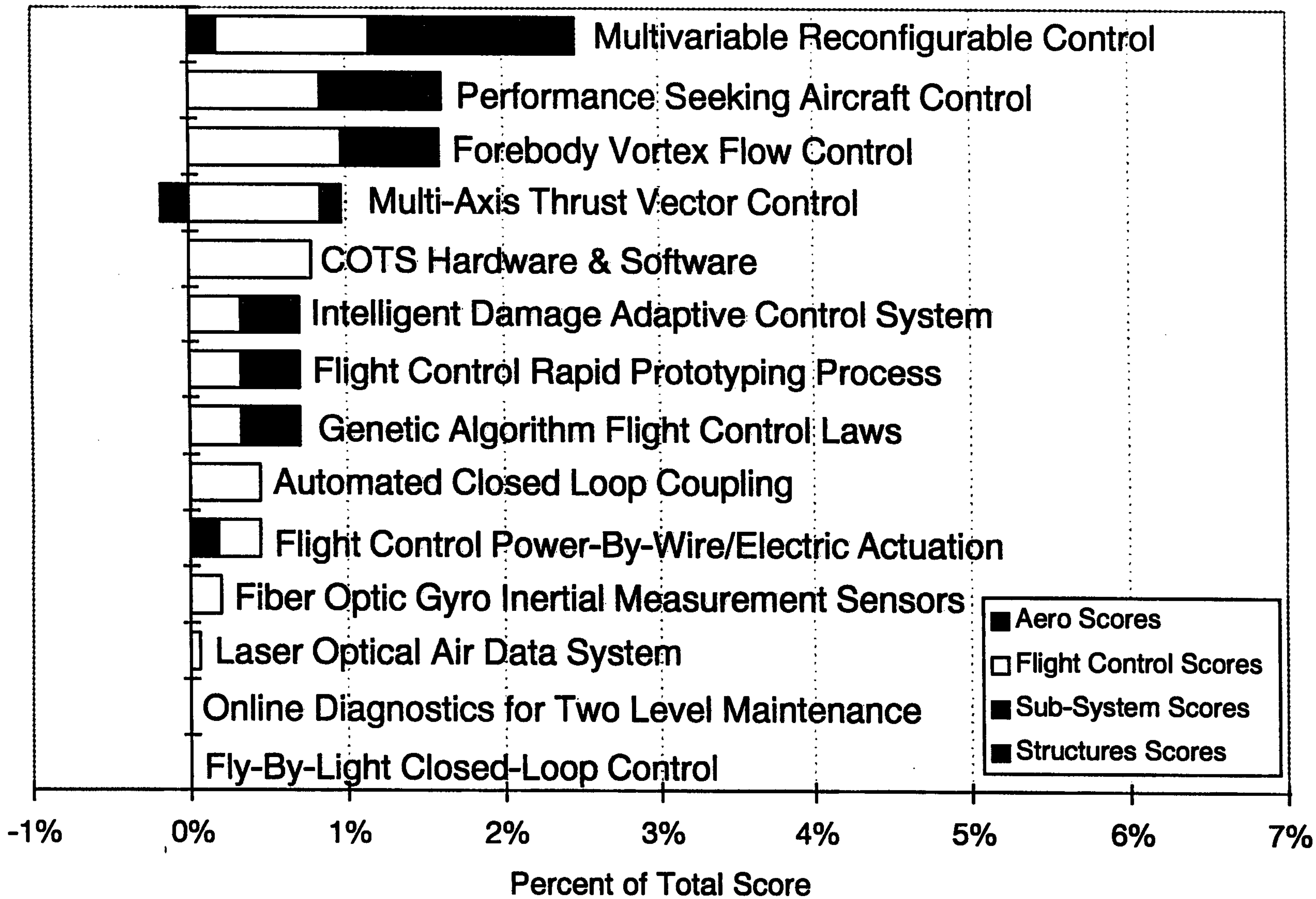


Flight Control Technologies - Performance Perspective

Flight Control technologies do not satisfy performance TEOs to as significant degree as the Aero technologies..

It it interesting to observe that where there is satisfaction it is about evenly split between Flight Control performance TEOs and Aero performance TEOs, i.e., there is about an equal amount of yellow and red.

Flight Control Technologies - Performance Perspective

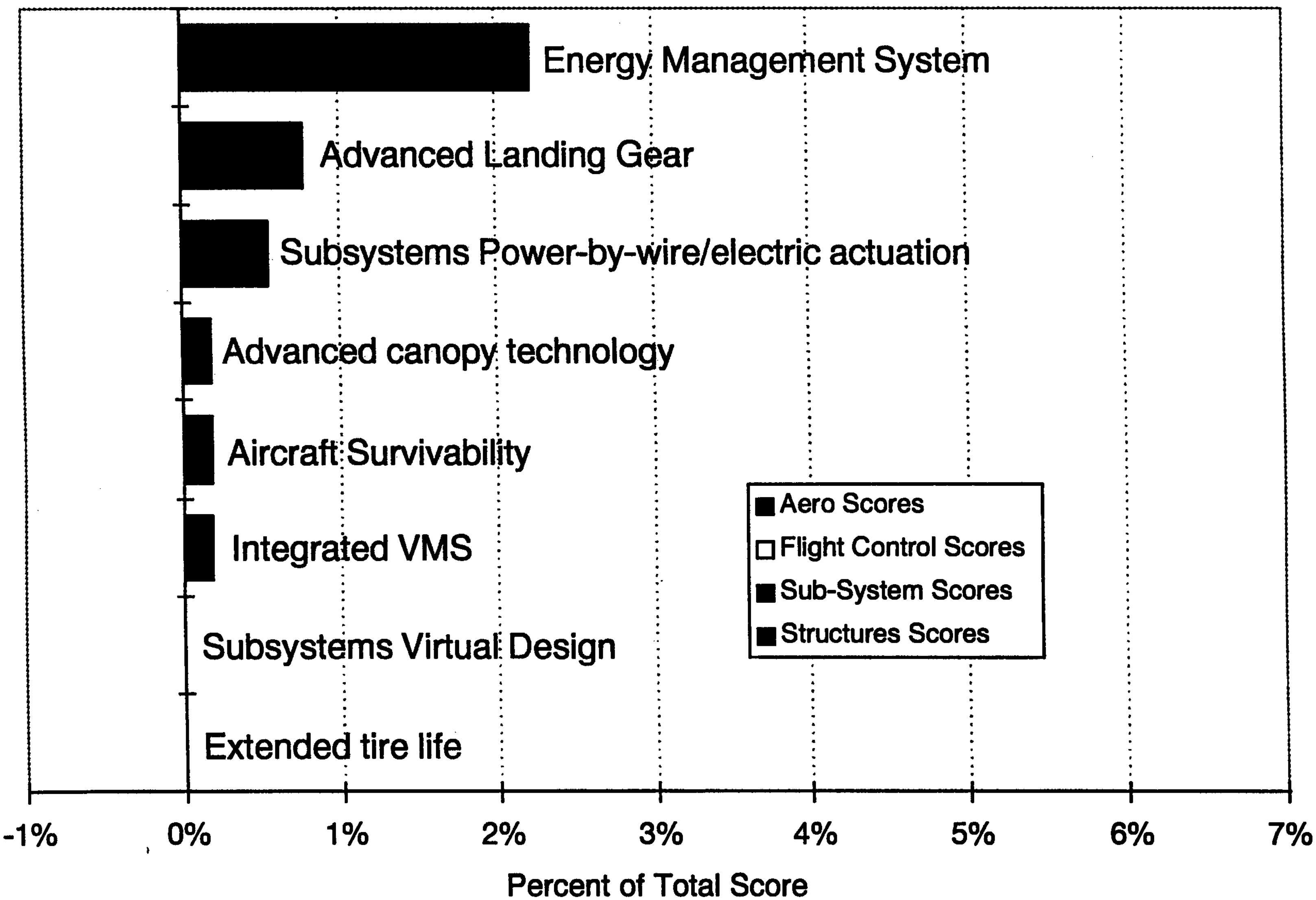


Sub-Systems Technologies - Performance Perspective

With the possible exception of 'Energy Management System', Sub-system technologies do not interact strongly with performance TEOs.

Where they do satisfy performance TEOs it is almost always a Sub-systems performance TEO (large amount of blue).

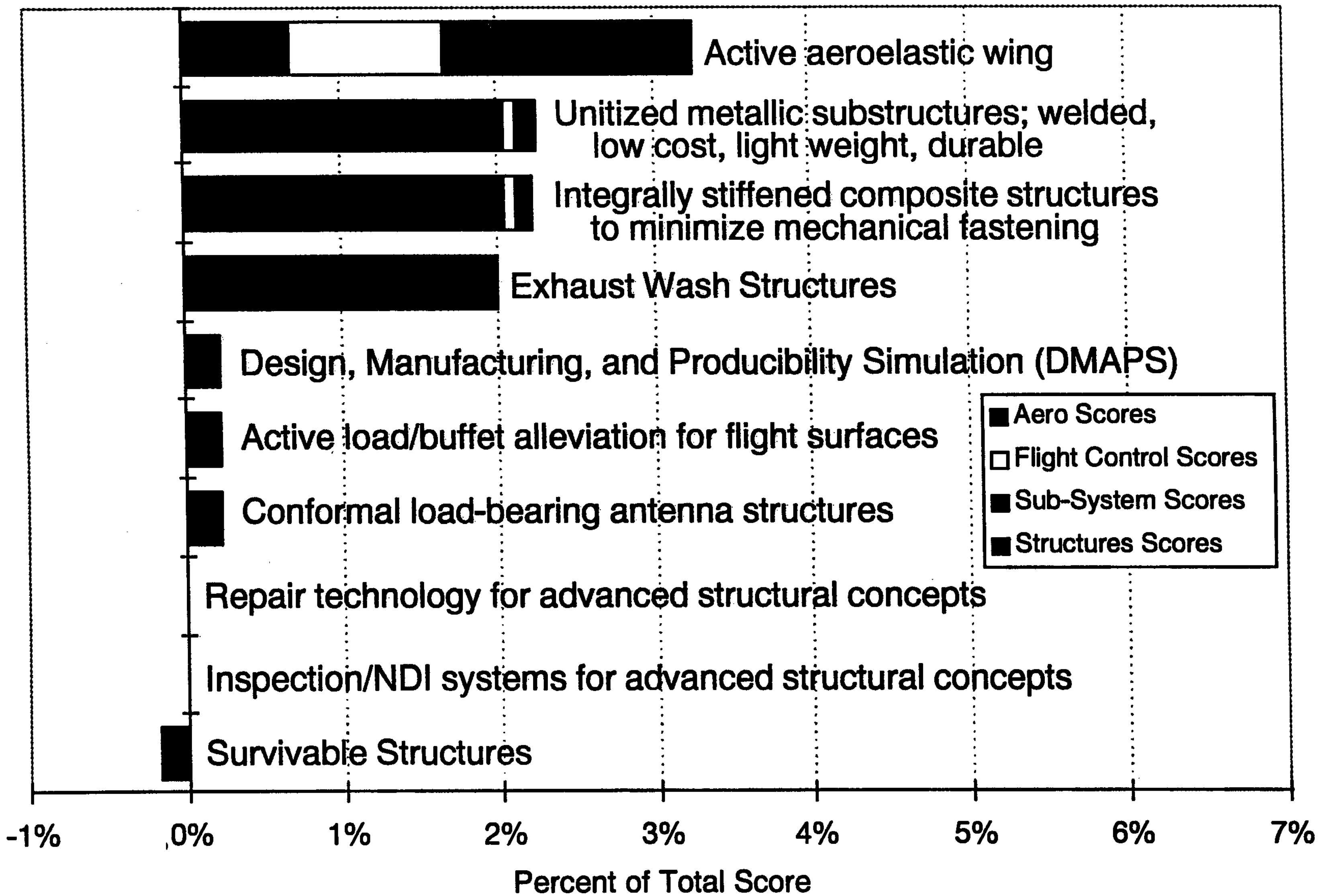
Sub-Systems Technologies - Performance Perspective



Structures Technologies - Performance Perspective

Structures technologies are more balanced, they about equally satisfy affordability TEOs and performance TEOs , as shown here,.

Structures Technologies - Performance Perspective



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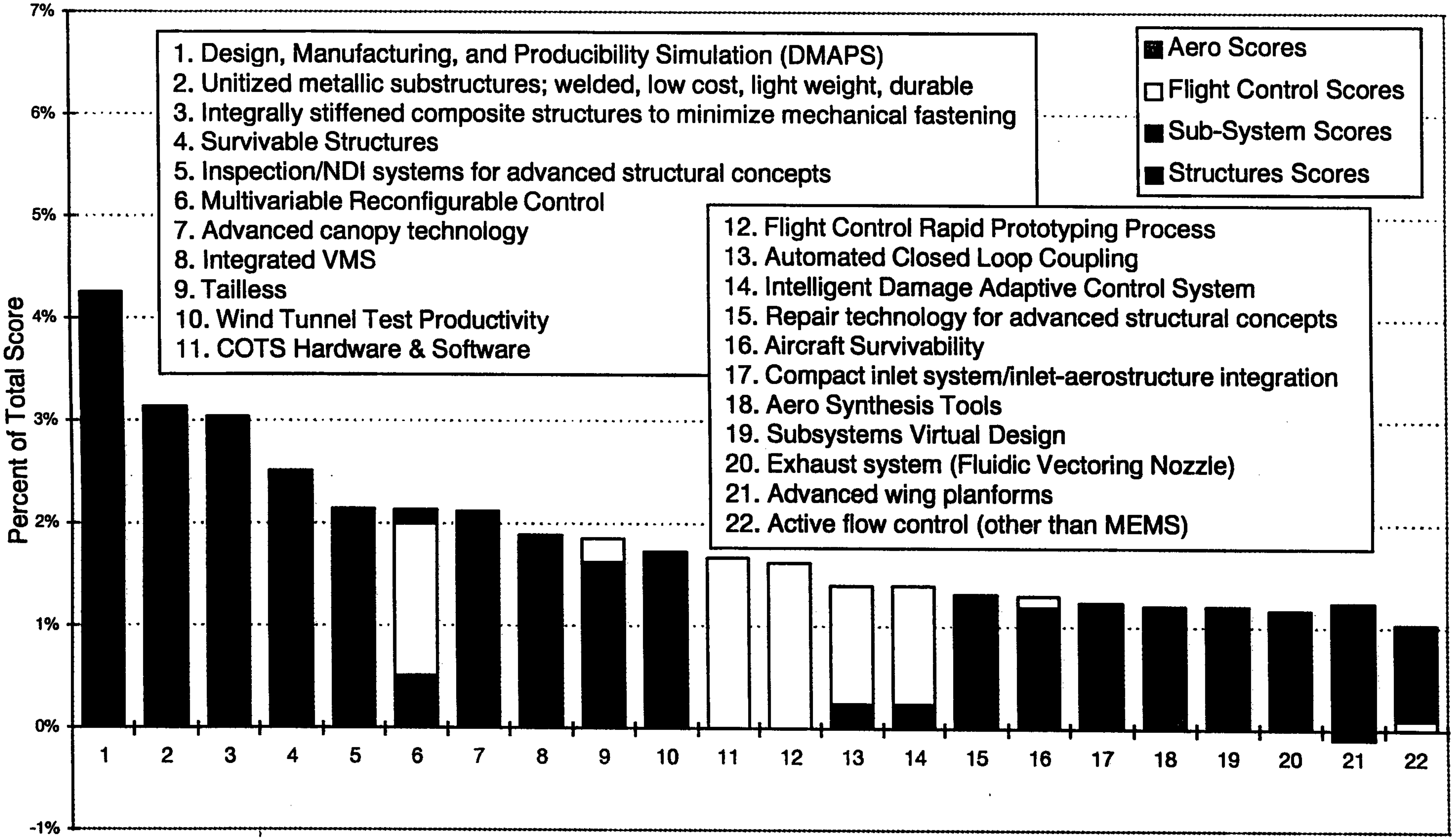
All Technologies - Affordability Perspective

Here are the top 22 of the 44 technologies stacked from their ability to satisfy just the 11 affordability TEOs. Every data point on this graph was previously presented but in four separate graphs. Before, the data was 'stovepiped' in traditional bins. Now the 44 technologies are grouped together.

From just an affordabily TEO satisfaction perspective, 'DMAPS' dominates by a significant margin over 40 of the 44 technologies.

The sum of all 44 bars presented on this page and the next is almost exactly 50%.

All Technologies - Affordability Perspective



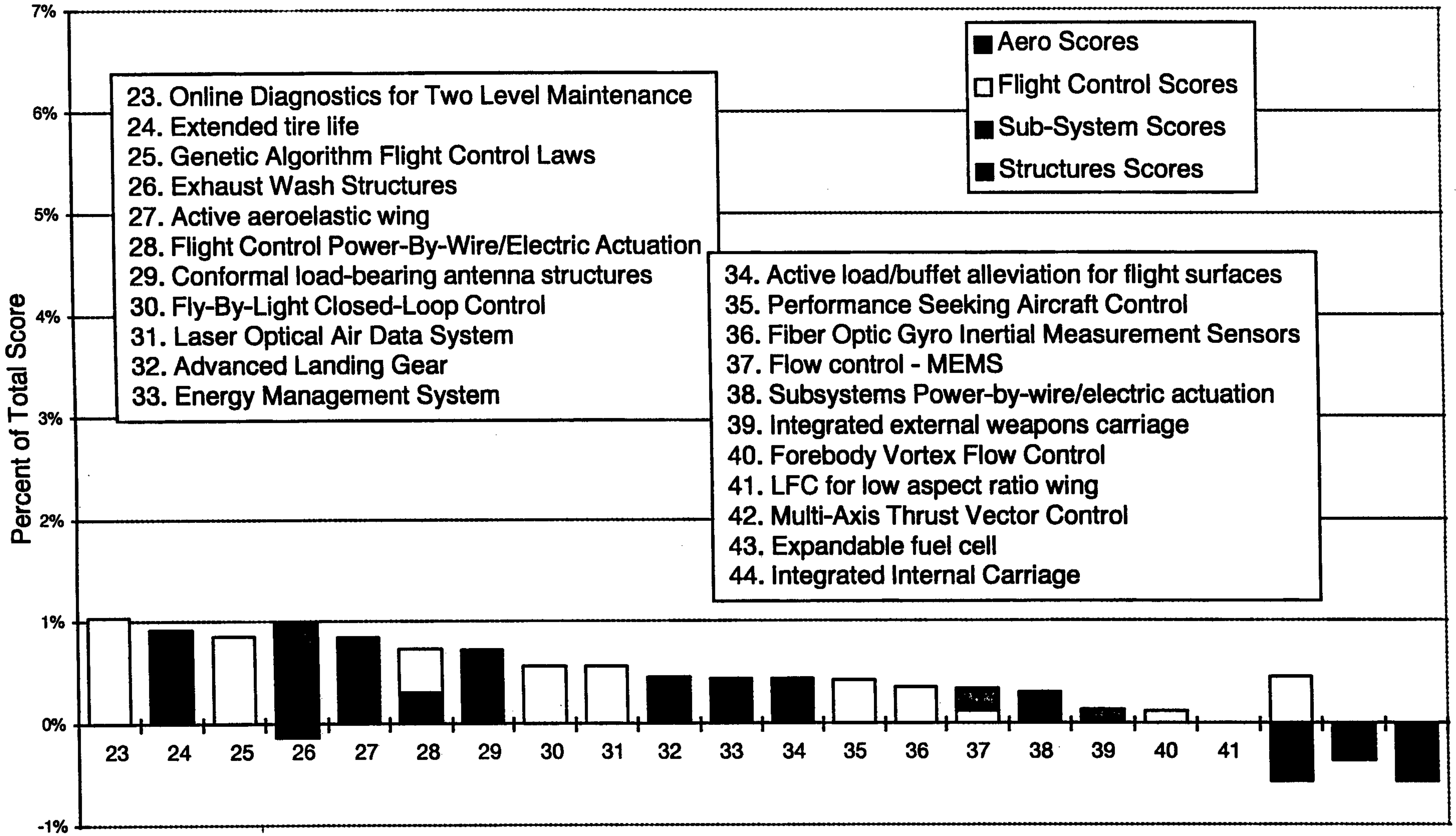
All Technologies - Affordability Perspective (Cont.)

Here are the remainder of the 44 technologies when assessed just in their ability to satisfy just the 11 affordability TEOs.

As illuminated earlier, the last two technologies offer no affordablity TEO satisfaction and #42, 'Multi-Axis Thrust Vector Control' offers a near equal amount of satisfaction and dissatisfaction.

A negative score in Matrix T indicates the respective technology did not contribute to the TEO, rather applying the technology to the FWV program would inhibit satisfying the TEO. An overall negative Matrix T score for a particular technology suggests that while the technology may be able to satisfy some TEOs, this satisfaction is overshadowed by one or more assessments where the technology inhibited the satisfaction of other TEOs.

All Technologies - Affordability Perspective (Cont.)

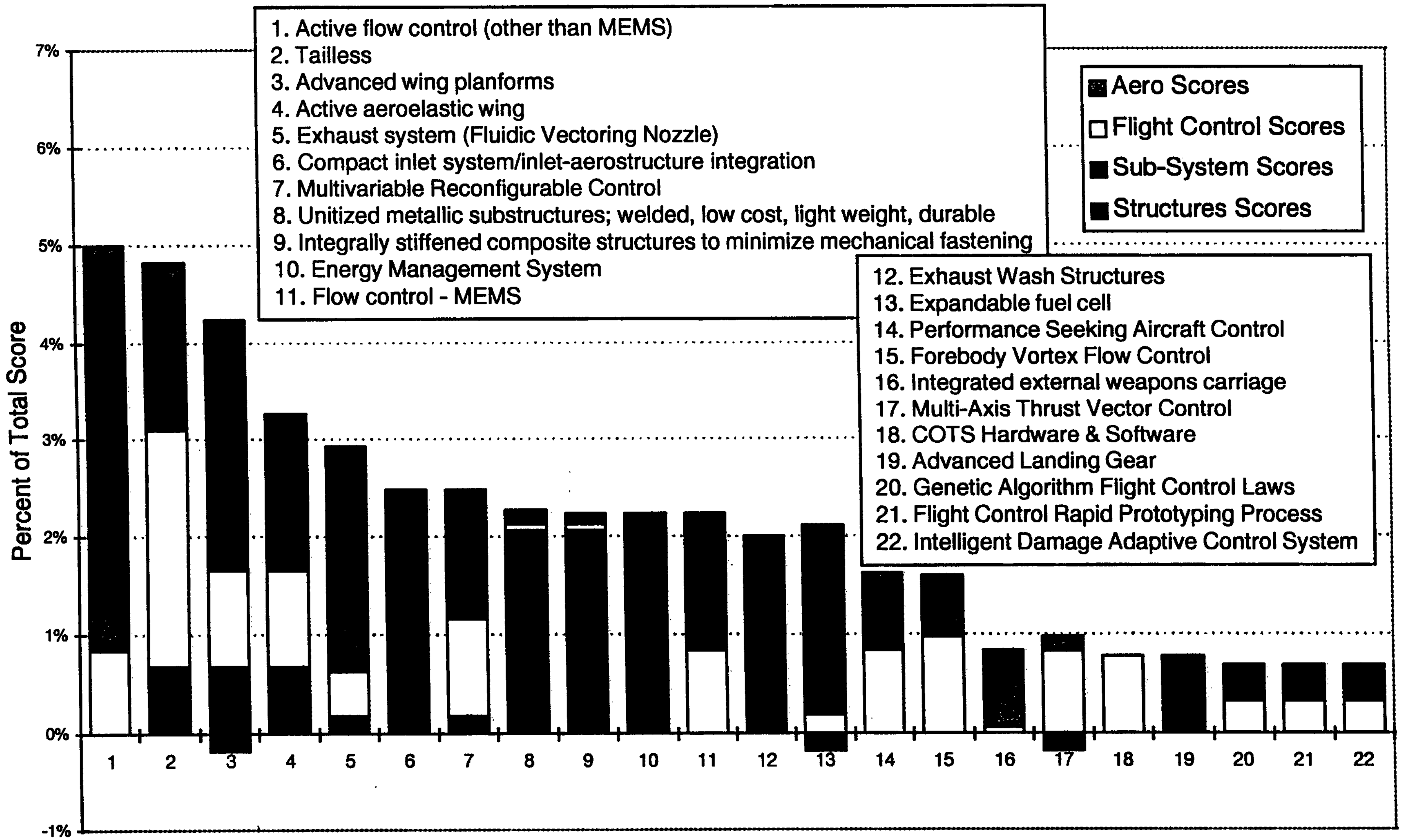


All Technologies - Performance Perspective

Here are first 22 of the 44 technologies when stacked from their ability to satisfy just the 10 performance TEOs. Note the heavy Aero TEO satisfaction in the leading technologies shown in red.

Like the two overall affordabilty only TEO satisfaction graphs, the sum of all 44 bars presented on this page and the next is almost exactly 50%..

All Technologies - Performance Perspective

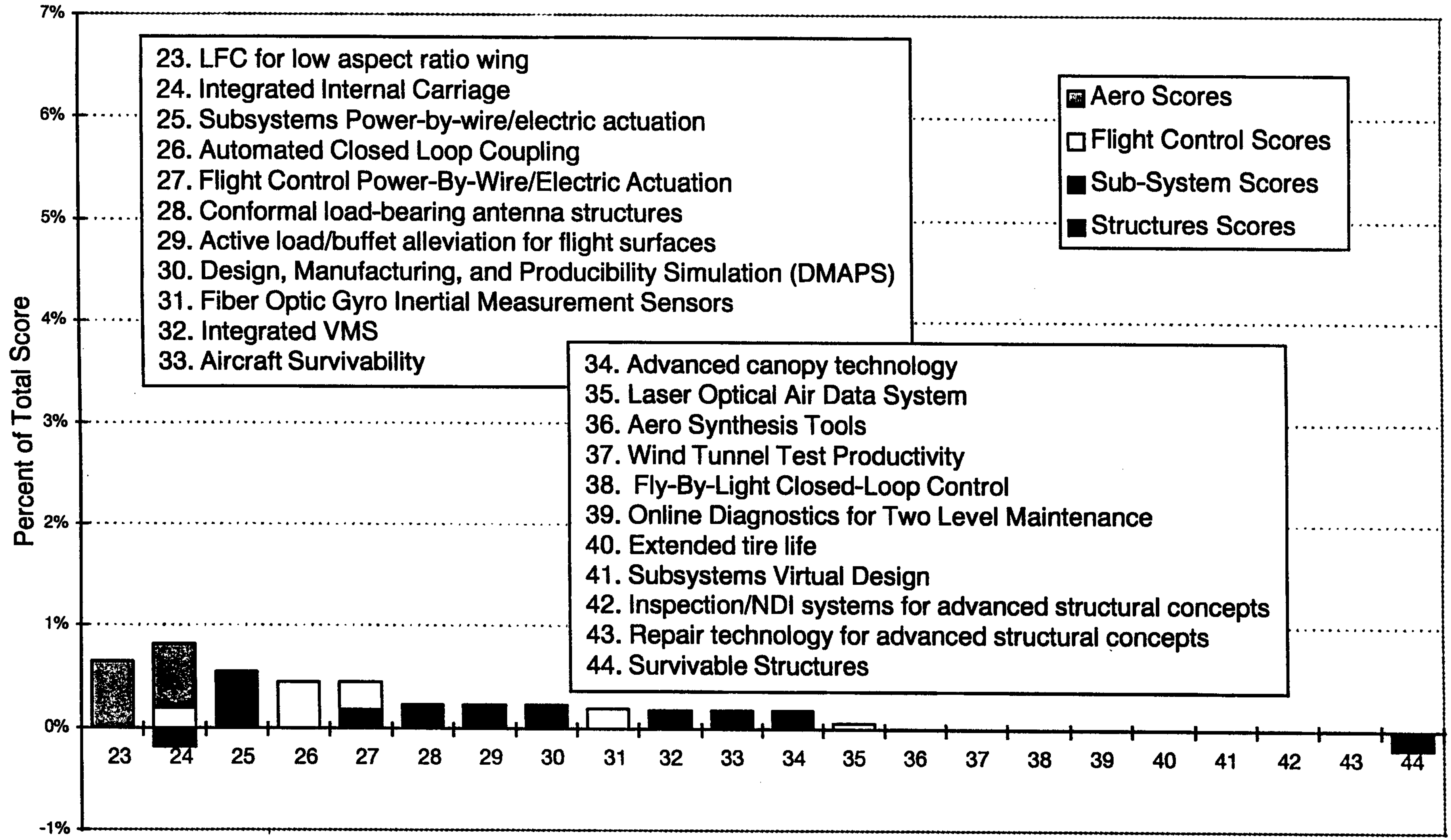


All Technologies - Performance Perspective (Cont.)

Here are the remainder of the 44 technologies when assessed just in their ability to satisfy just the 10 performance TEOs.

Note, a number of technologies (#s 28-43) make very little, or no, contribution to satisfying performance TEOs.

All Technologies - Performance Perspective (Cont.)



All Technologies - Combined Perspective

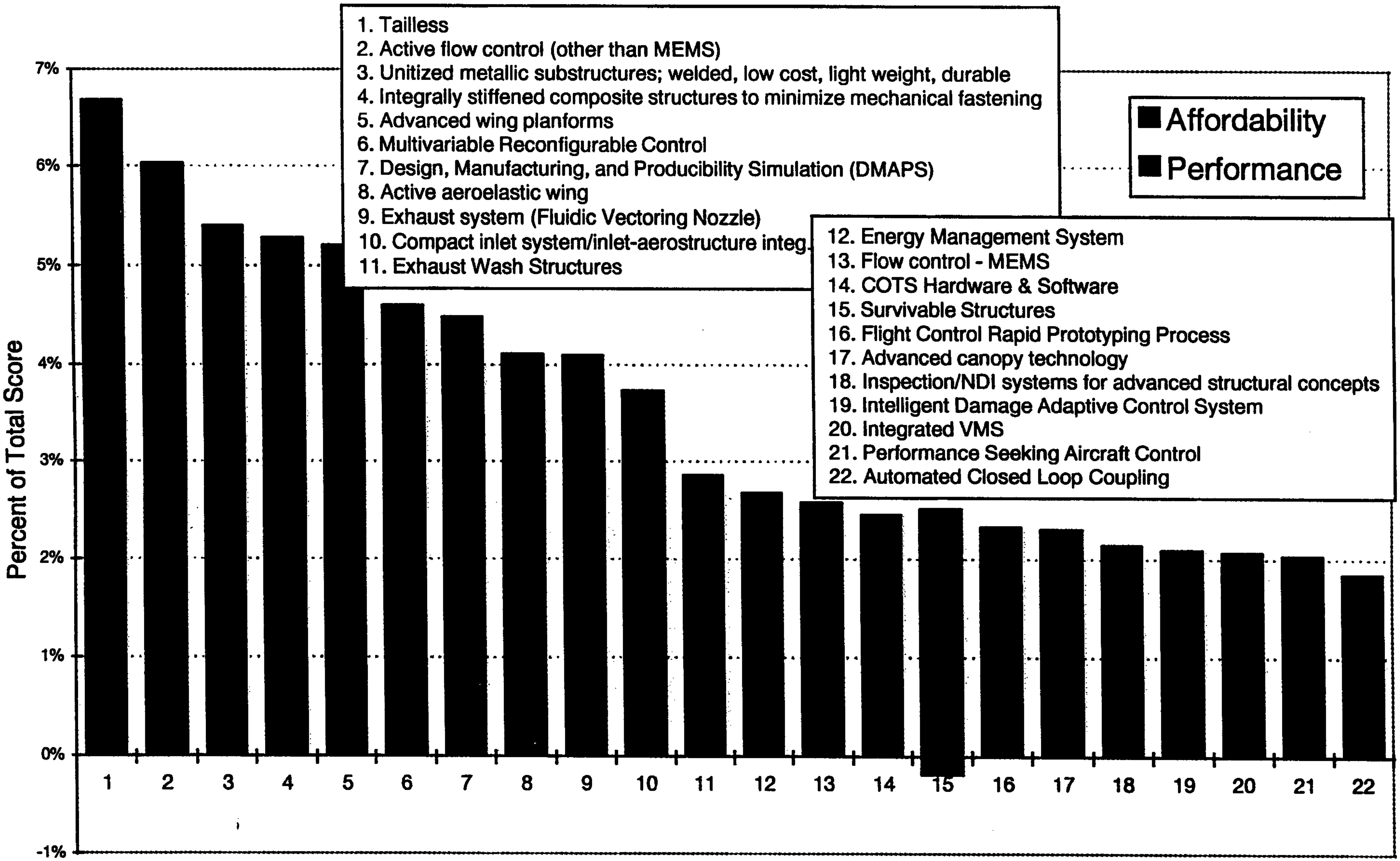
The next two charts summarize the previous four.

Here the first 22 of the 44 technologies are stacked with their combined ability to satisfy the 11 affordability and 10 performance TEOs.

'Tailless' satisfied the performance TEOs better than any other technology and it was competitive with the bulk of the technologies in satisfying affordabilty TEOs. When the two perspectives are combined, this graph suggests that 'Tailless' does the best overall job of satisfying the complete set of 21 TEOs.

There appears to be a 'break' in the curve between technology #10 and #11. In other words, the QFD data suggests that 10 of the 44 technologies are the most beneficial in satisfying FWV TEOs and hence, FWV Sub-Area Goals and hence, the FWV Aircraft Payoffs.

All Technologies - Combined Perspective



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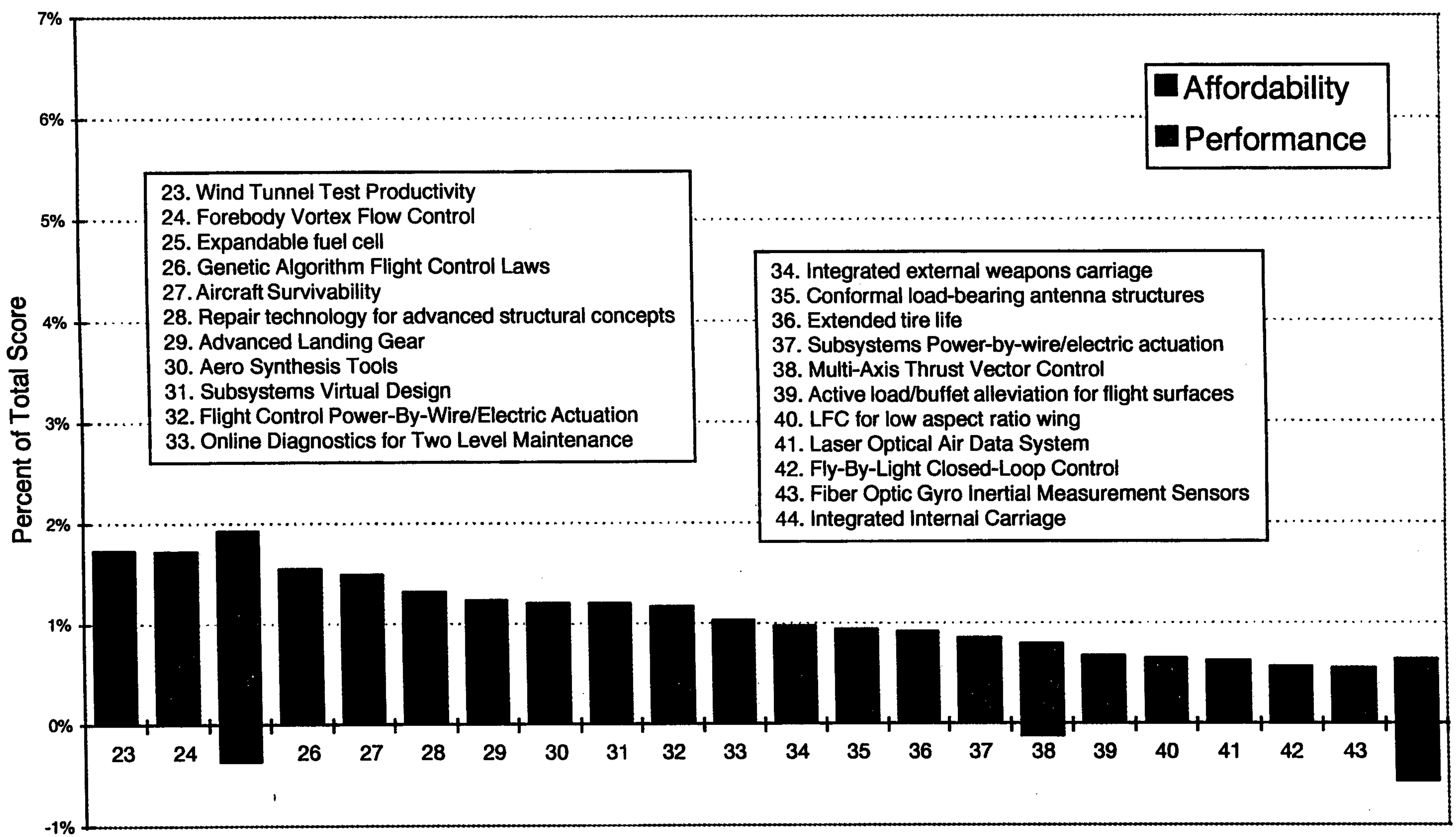
All Technologies - Combined Perspective (Cont.)

It is more difficult to distinguish a second 'break' in this output plot.

What is interesting is that the top 10 technologies account for almost 50% of the output emphasis. The remaining 50% is distributed among the other 34 technologies.

All Technologies - Combined Perspective (Cont.)



Investment to Reach Technology Level 6

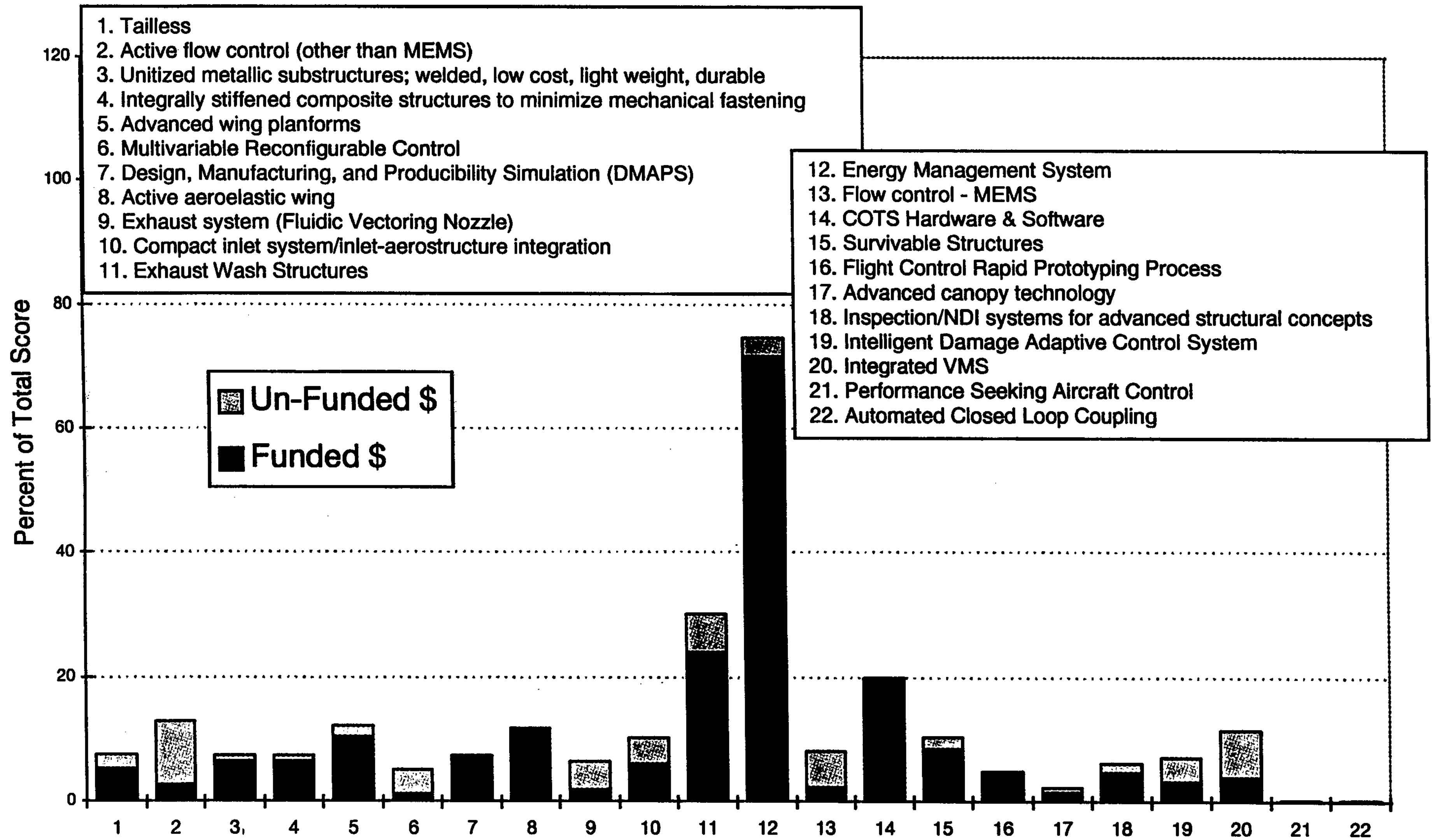
An additional piece of the FWV QFD analysis was an estimate of the investment required for each technology to reach Technology Readiness Level (TRL) 6 by 2003.

This cost data was estimated by the Boeing STL technology team leaders in $M of unfunded technology investment and already funded technology investment. The combination of the two estimates was used as an additional piece of data with which to examine the attractiveness of the top 10 technologies suggested by the QFD scores.

The technologies shown on this page, and the next page, are ordered as they appeared when sorted by their ability to satisfy both affordability and performance goals.

Of all the investment cost estimates made by the Boeing STL technology team leaders, #12 'Energy Management System' was by far the highest. However, as previously noted, this investment covers several technologies and the J/IST TEMM of $50M included in the total may be adequate to reach TRL #6 without the need of a flight test.

Investment to Reach Technology Level 6



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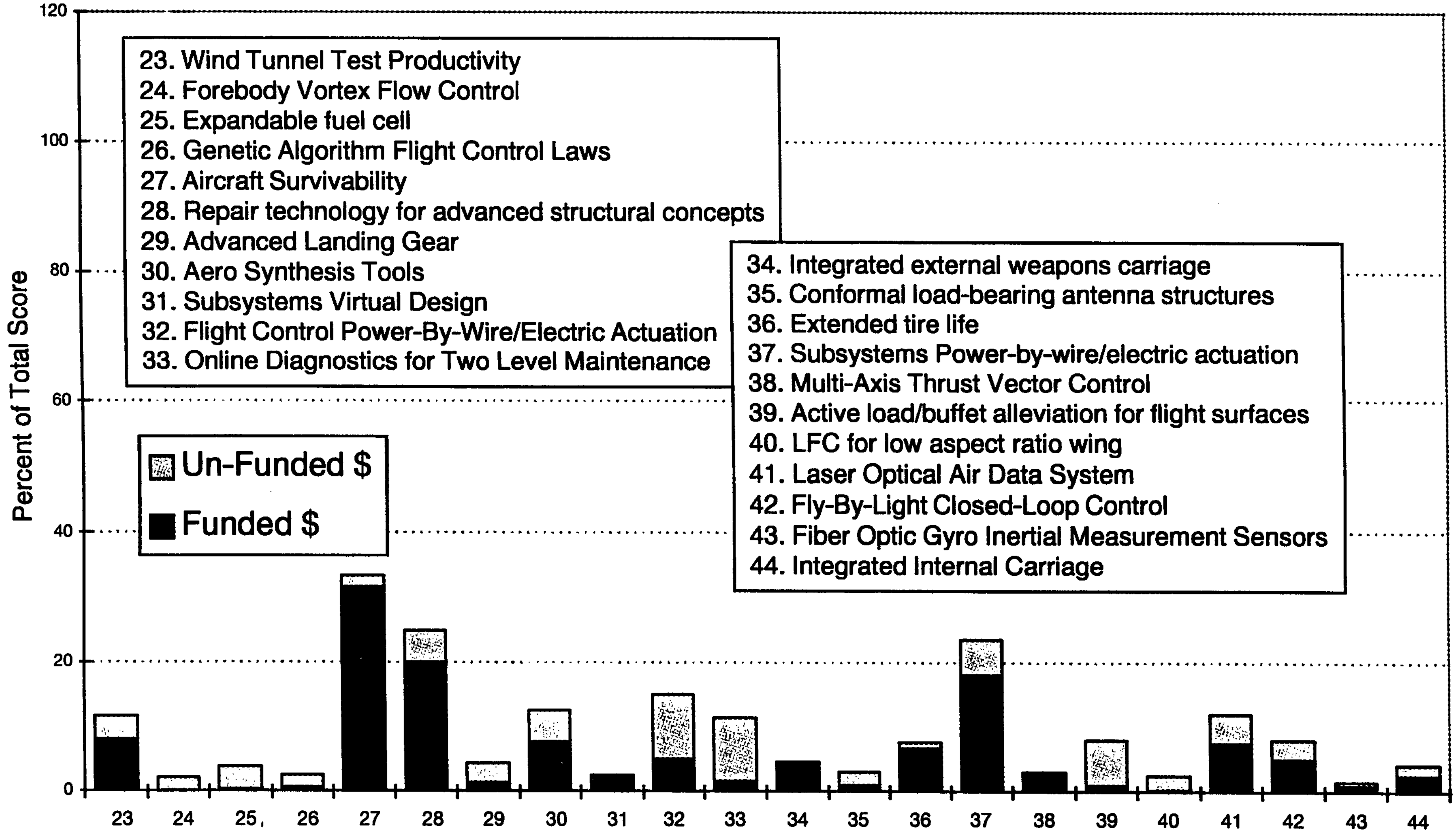
Investment to Reach Technology Level 6 (Cont.)

Here are the remainder of the 44 technology investment cost estimates.

Investment to Reach Technology Level 6 (Cont.)



Affordability Only Map

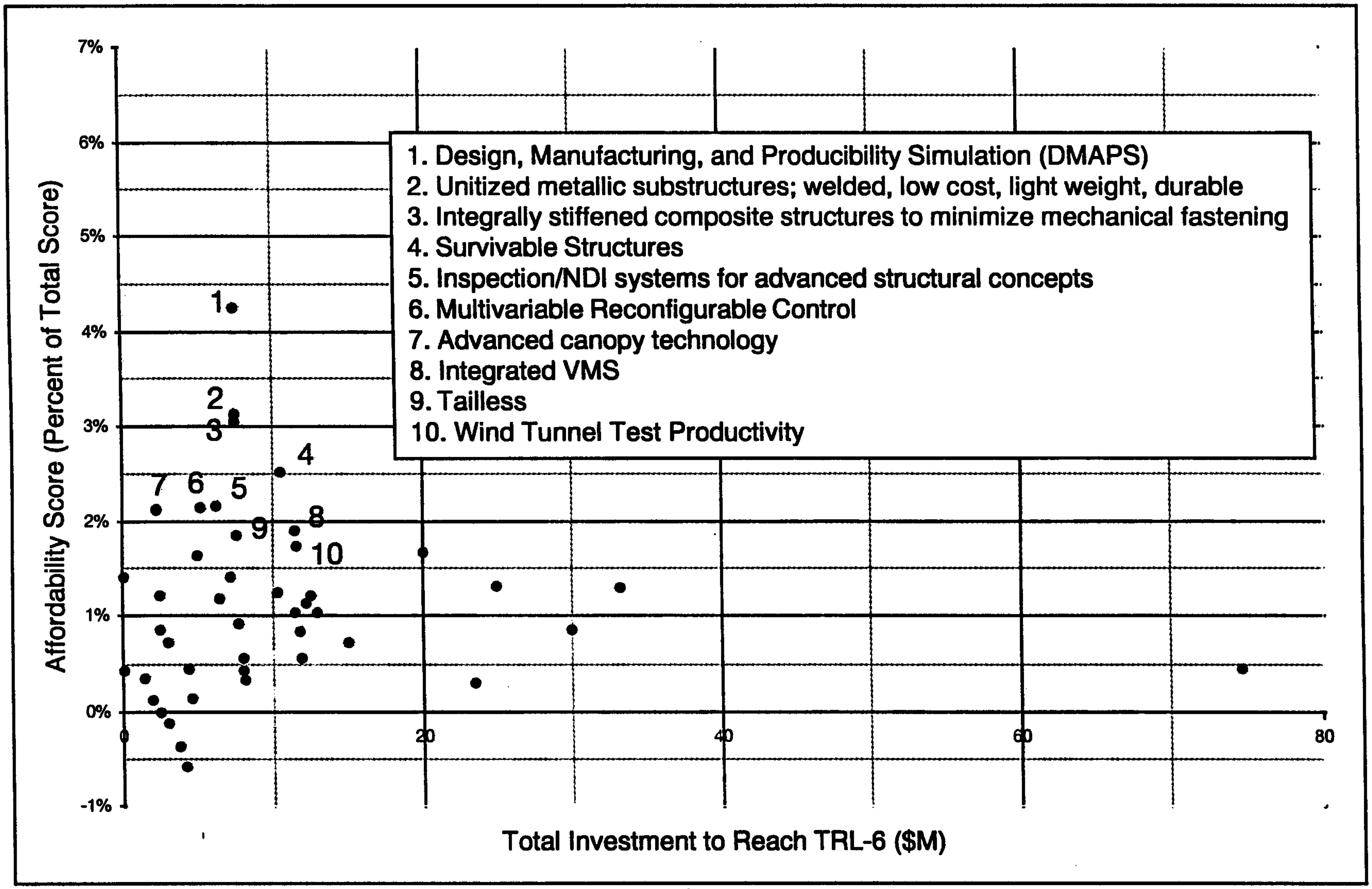
Plotted here on the vertical axis are the QFD scores representing the 44 technology's ability to satisfy just the 11 affordability TEOs and on the horizontal axis the total investment estimates ($M) to reach TRL 6 in 2003. High QFD scores and low investment would be the preference.

What emerges is a suggestion that the top 10 technologies from the QFD scoring are also attractive because relative to the other 34 technologies they do not appear overly costly to reach TRL 6.

Data points that lie on the extremes of a plot like this deserve special attention. Over to the far right is 'Energy Management System', is this correct?

Affordability Only Map

Investment to reach TRL 6 vs.
Affordability Perspective



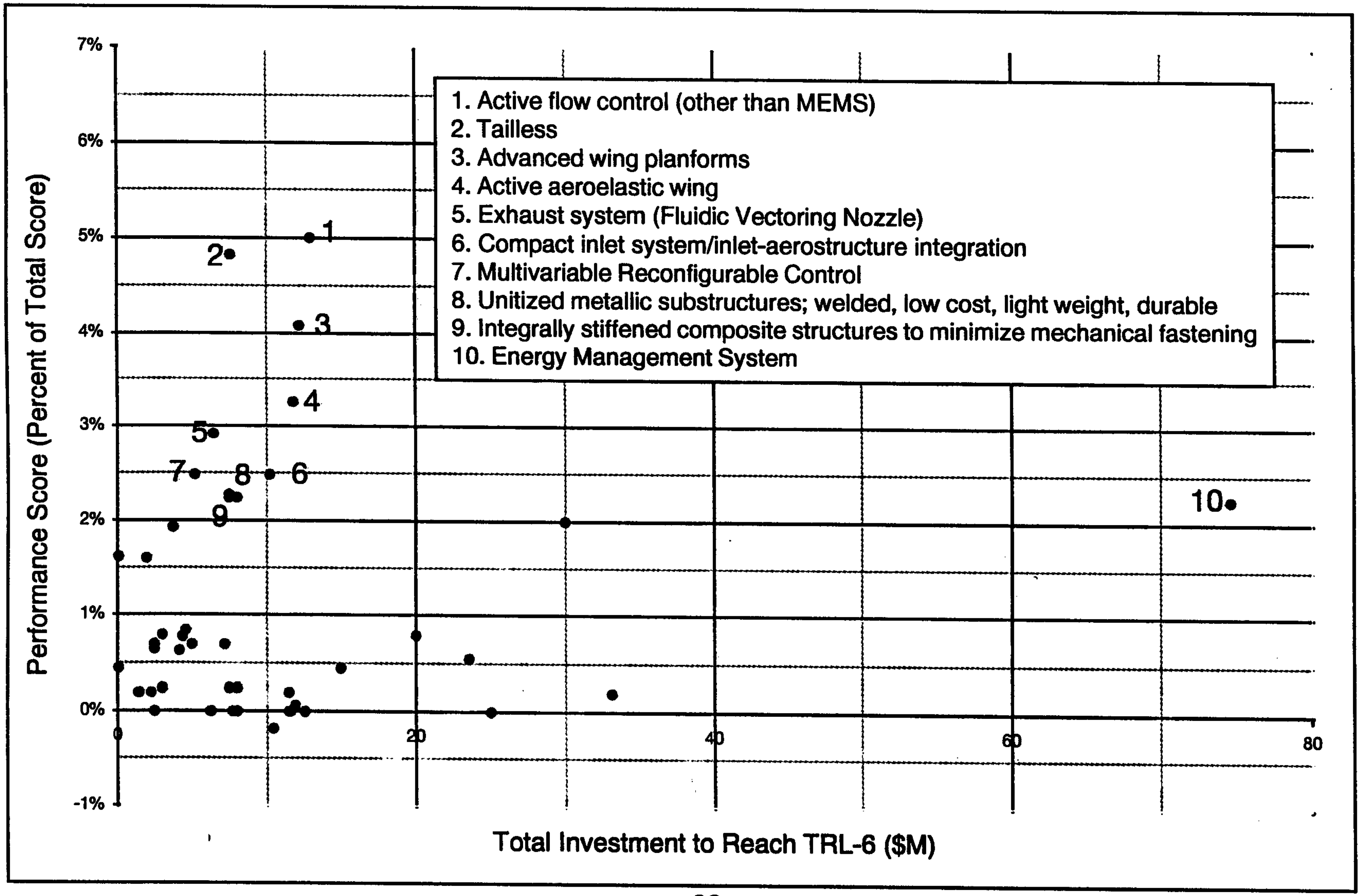
Performance Only Map

Here is the same plot, only now the vertical axis represents the QFD score attained satisfying just the 10 performance TEOs.

A similar picture emerges with a grouping to the top 9 QFD scoring technologies appearing investment cost competitive with the others. Note that #10, from a QFD score perspective, is now 'Energy Management System' and because it is so costly would almost certainly not be considered overall as attractive as #s 1-9, except that #s 1-9 require flight test in a new vehicle and that cost is not included.

Performance Only Map

Investment to reach TRL 6 vs. Performance Perspective



Affordability + Performance Map

Finally the combined perspective of technologies satisfying both affordablity and performance TEOs emerges.

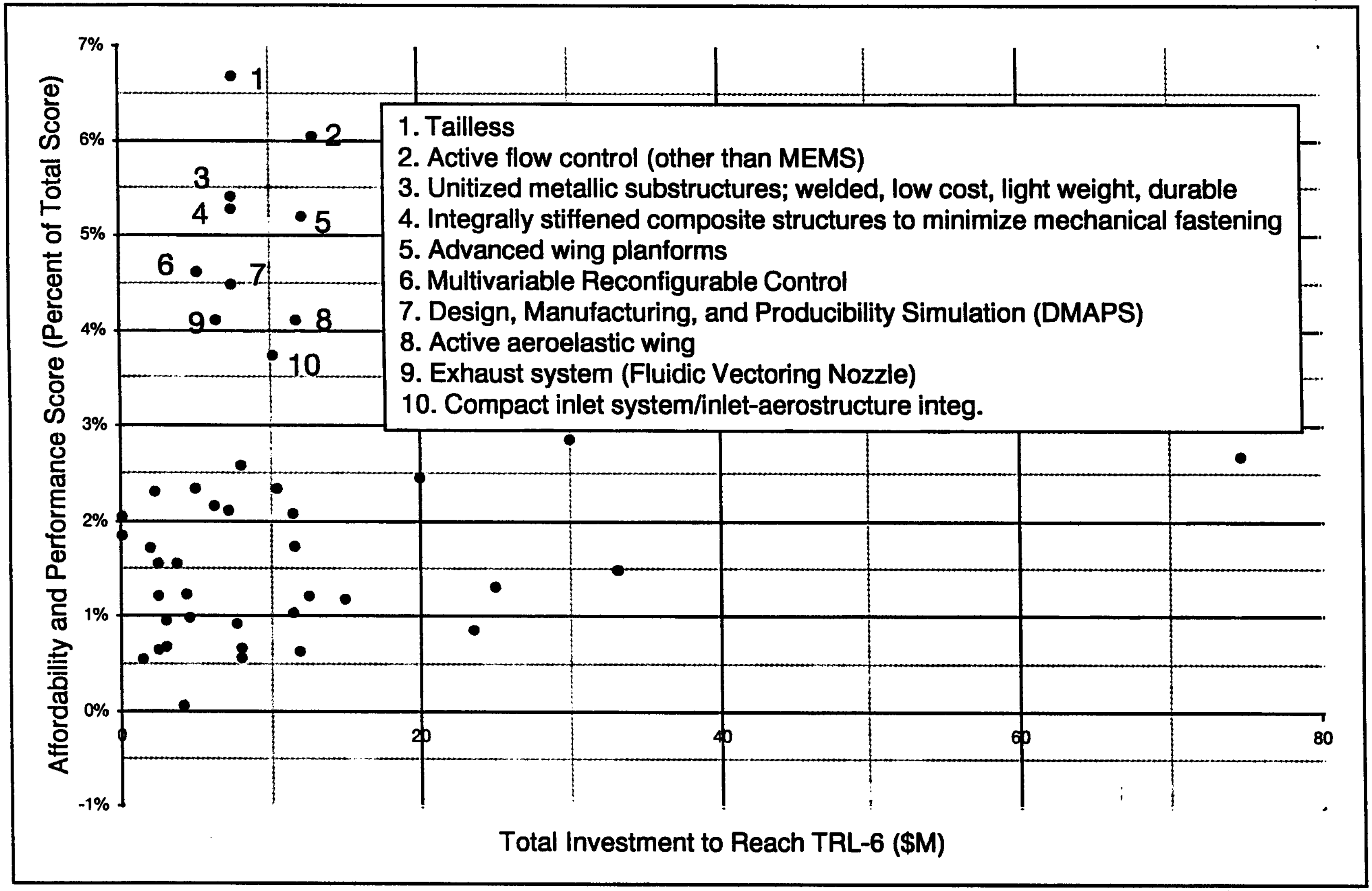
This plot is a sum, in the vertical axis, of the previous two.

A clearer grouping appears to the upper left combining the high scoring technologies from the two segregated perspectives. Examine 'Tailless', note that the QFD score here of ~7% is the sum of the affordability score of 2% and the performance score of 5%..

Before the conclusion was drawn that this is a natural grouping of the top 10 technologies, a final perspective was entertained. What was the ratio of QFD performance score divided by investment cost estimate, i.e., "benefit-to-cost" ratio?

Affordability + Performance Map

Investment to reach TRL 6 vs.
Affordability and Performance Perspective



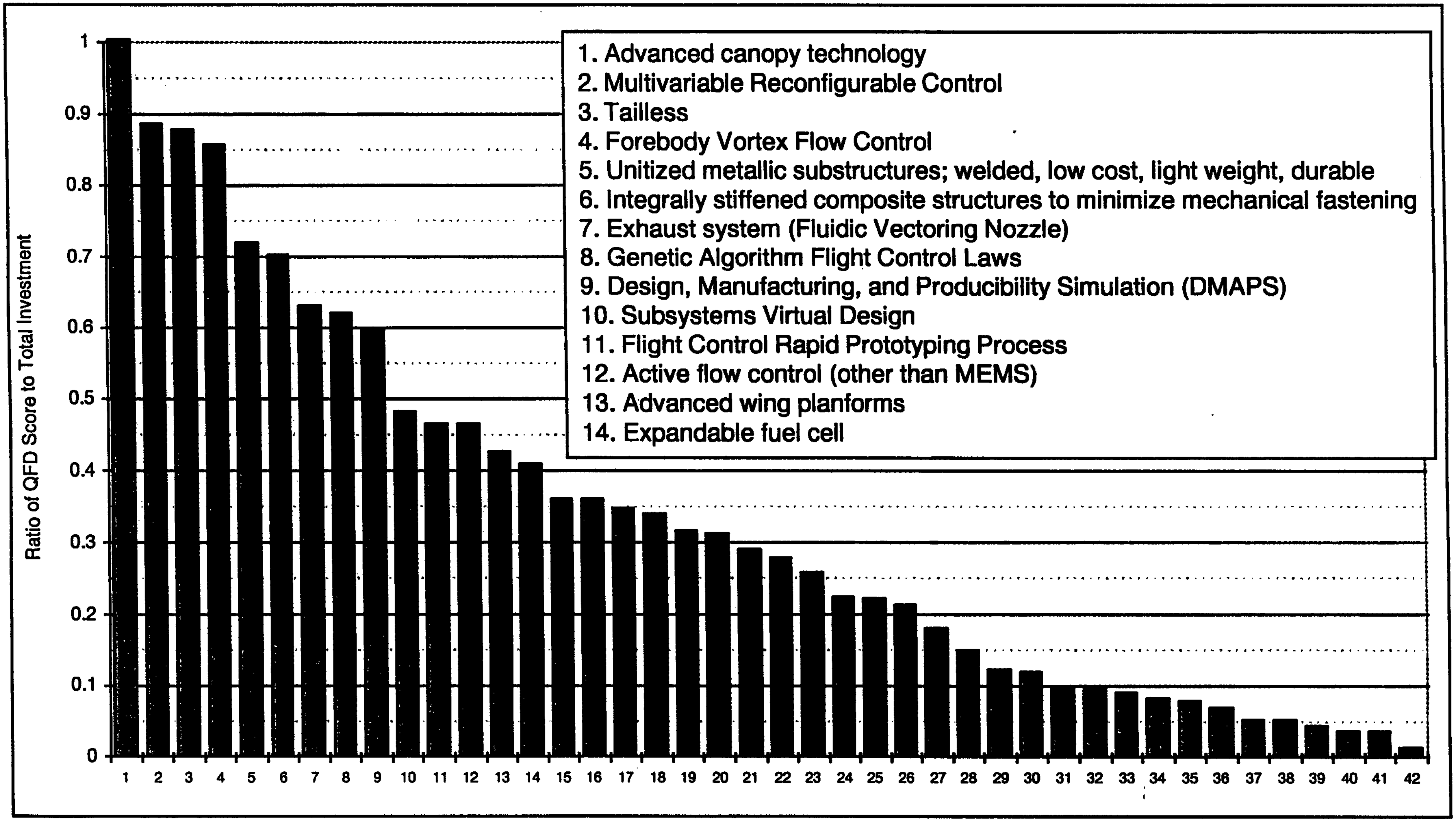
Ratio of QFD Score to Investment to Reach TRL 6

This sorted stack represents the result of computing this ratio. Technologies that have a high QFD score and were estimated to be the cheapest investments to reach TRL 6 populate the left side of this chart.

Even though 'Advanced Canopy Technology' did not show up in the top 10 grouping on the combined plot refer back to the affordability only map where it was in the top grouping. Overall then, 'Advanced Canopy Technology' even though with a smaller QFD score had a sufficiently small investment estimate that the ratio of the two parameters suggests that this should be the first technology funded for the FWV program because is provides the most FWV goal satisfaction for the investment.

There appears to be a break in the slope of this graph in the neighborhood of technology #10-14. The top 14 technologies from this perspective are highlighted for future comparison with the top 14 from the previous combined affordability and performance TEO satisfaction perspective.

Ratio of QFD Score to Investment to Reach TRL 6



Performance Seeking Aircraft Control and Automated Closed Loop Coupling Technologies are Currently at TRL - 6

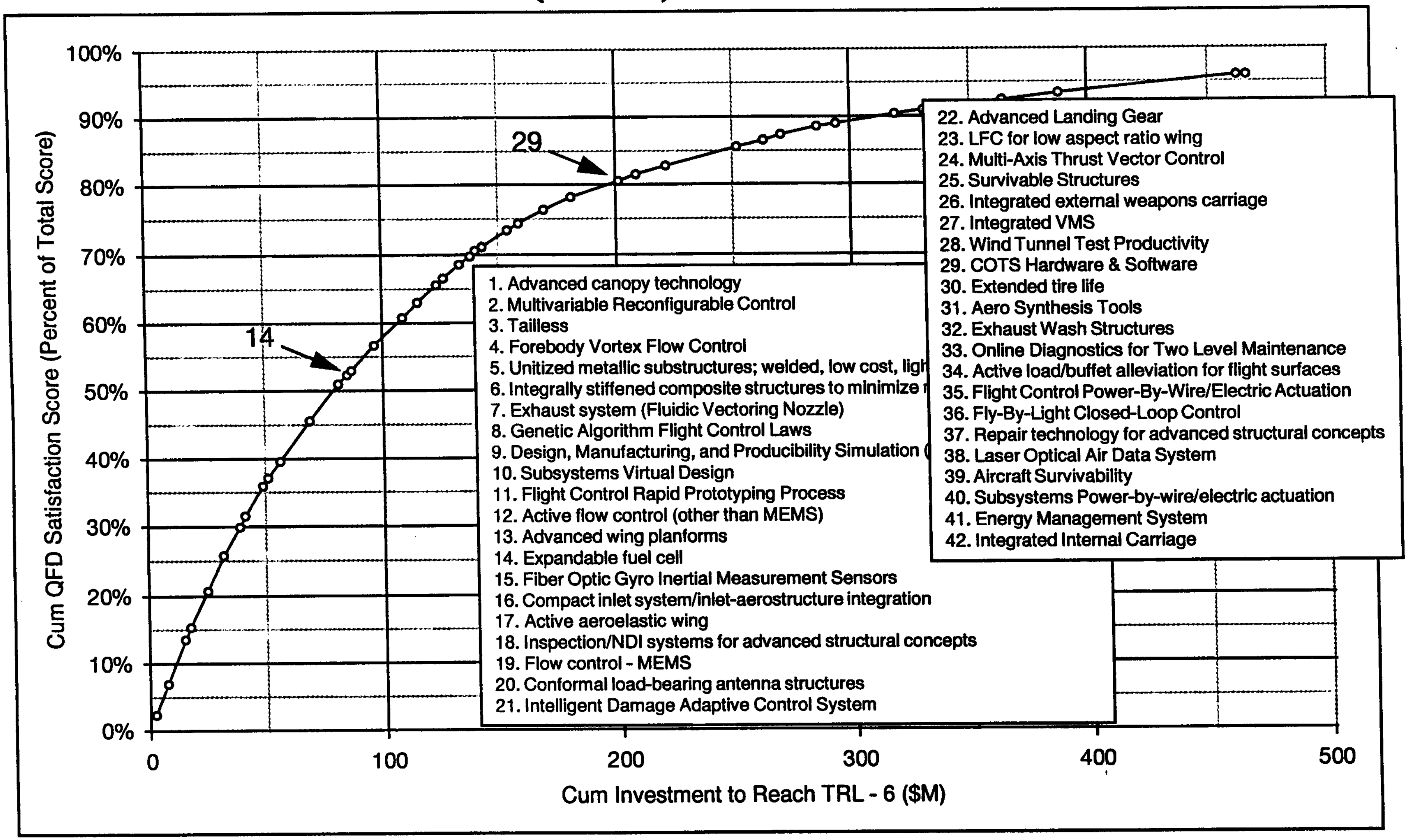
Technologies Available for Given Investment ($M) to Reach TRL 6

This is the same data presented on the previous page but now added cumulatively moving across the horizontal axis.

First, observe that all 44 technologies are ordered by their QFD goal satisfaction score / investment cost ("bang-for-the-buck"), the same order as presented on the previous page.

Secondly, funding the top 14 technologies with $100M will satisfy over 50% of the FWV TEOs. Funding the top 29 technologies with $200M will satisfy ~80% of the FWV TEOs.

Technologies Available for Given Investment ($M) to Reach TRL 6



Conclusion - Customer Perspective is Critical

These 14 technologies are presented as the highest priority candidates of the 44 technologies evaluated for the FWV program. It is critical to emphasize that this list represents a cross between two different conclusion perspectives, a FWV goal satisfaction only and a benefit-to-cost ratio, and therefore which perspective is valued would make a difference in the ultimate selections. The order of this list was produced by dividing the qualitative QFD score by the estimated investment cost necessary to reach Technology Readiness Level 6 in 2003.

The only technologies not offered in this top grouping that were shown in the map of combined affordability and performance TEO satisfaction are; 'Compact Inlet System / Inlet-Aerostructure Integration' and 'Active Aeroelastic Wing' . Their cost estimates were higher than any of the top 14, thus lowering their benefit-to-cost ratios.

Technologies shaded red had higher QFD scores. High QFD scores should be interpreted as stronger satisfaction of FWV Technology Element Objective (TEO) goals. However, the investment cost for these technologies is generally larger than for those shaded black.

If TEO goal satisfaction is more important than low investment cost, then only the technologies shaded red would be preferred. If the ratio of benefit verses cost is more important, then the rank order presented in this list would be preferred.

Conclusion - Customer Perspective is Critical

Top Technologies Sorted by Ratio of QFD Score to Investment

1. **Advanced canopy technology**
2. Multivariable Reconfigurable Control
3. Tailless
4. **Forebody Vortex Flow Control**
5. Unitized metallic substructures; welded, low cost, light weight, durable
6. Integrally stiffened composite structures to minimize mechanical fastening
7. Exhaust system (Fluidic Vectoring Nozzle)
8. **Genetic Algorithm Flight Control Laws**
9. Design, Manufacturing, and Producibility Simulation (DMAPS)
10. **Subsystems Virtual Design**
11. **Flight Control Rapid Prototyping Process**
12. Active flow control (other than MEMS)
13. Advanced wing planforms
14. **Expandable fuel cell**

Technologies with High QFD Scores

Technologies with Lower QFD Scores, but Lower Investment Required

FWV Technologies Applicable to UCAV

The QFD results previously discussed were based on the FWV technologies being applied to a manned vehicle. WL/FI asked Boeing-Phantom Works to identify which of the FWV technologies would also be applicable to an unmanned combat air vehicle. Our approach to this request and the results are discussed here.

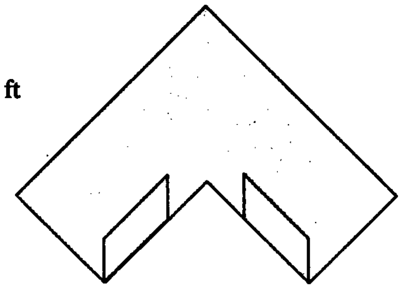
FWV Technologies Applicable to UCAV

SEAD Vehicle Concepts

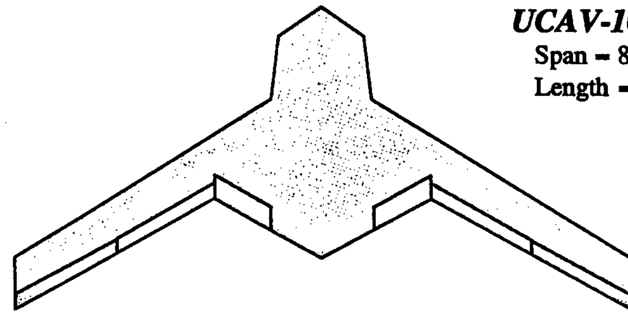
The Phantom Works conducted a UCAV study for NASA LaRC to identify revolutionary capabilities and technologies. The family of SEAD concepts shown were defined during the study and were used to determine technology features that would enhance the effectiveness of these SEAD concepts.

SEAD Vehicle Concepts

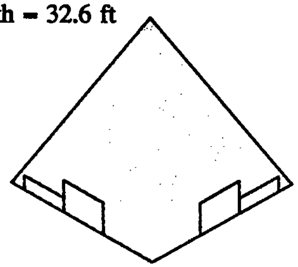
UCAV-1001
Span = 50.0 ft
Length = 36.7 ft



UCAV-1005
Span = 81.0 ft
Length = 40.1ft



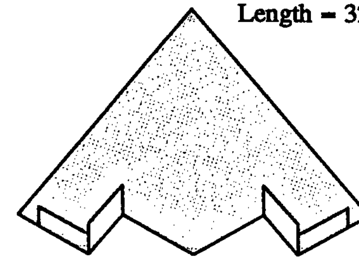
UCAV-1002
Span = 36.7 ft
Length = 32.6 ft



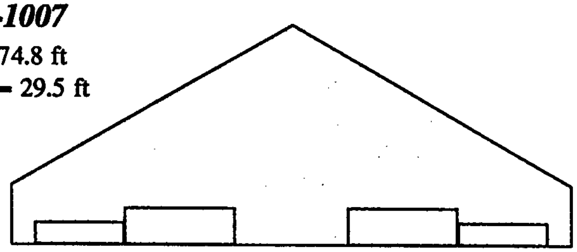
Performance Objective Ranges

- Mission Radius ~ 600 to 1000 nm
- Loiter @ 1000 nm ~ 30 min to 3 hours
- Gross Weight ~20,000 lb
- Speed - High Subsonic
- Payload - 2000 lb

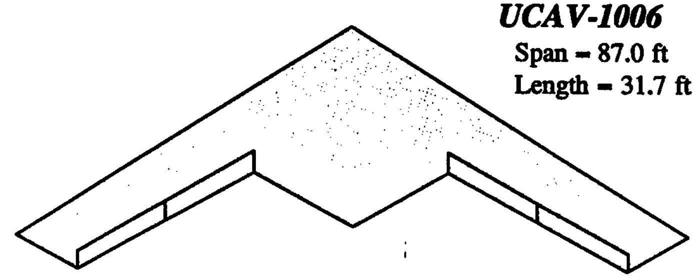
UCAV-1003
Span = 45.7 ft
Length = 32.6 ft



UCAV-1007
Span = 74.8 ft
Length = 29.5 ft



UCAV-1006
Span = 87.0 ft
Length = 31.7 ft



Planforms to Scale

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Desired UCAV (SEAD) Technology Features

This chart highlights desired technology features that were identified in the NASA LaRC UCAV study for the SEAD vehicle concepts. These desired features have been segregated into major technical areas. The technical areas highlighted in red are being addressed by the FWV program. Thus, an assessment was made to determine which FWV technologies address these desired SEAD vehicle technical features. The results are highlighted in the following charts for each of the four FWV technology thrust areas. Namely, Aeromechanics, Flight Controls, Structures, and Subsystems.

Desired UCAV (SEAD) Technology Features

Aero/S&C
- Tailless Control w/ no ML Breaks
- Innovative Weapons Release/Sep.
- Aero Control in Unconventional Flt.
- Intelligent Reconfigureable Controls
- Reduced Control Redundancy

Strct/Mat
- New Structural & Material Concepts
- Smart Sensing Materials
- Structurally Embedded Apertures

Mfg.
- LC Injection Moldings (Ribs)
- Protruded Spars
- HS Machined/EB Welded Unitized Structure
- Large LTC Composite Skins
- Substructure Bonded to Skins

Subsystems
- Integrated Subsystems for UCAV Applications

Propulsion
- Fixed Geometry Yaw Vectoring Nozzle
- Semi-Flush, Upper Mounted, Diverterless Inlet
- Efficeint, High Altitude Engine Operation
- UCAV Specific Prop Sys Cost Reduction

Propulsion continued
- Lubeless/Air Cooled Engines
- Improved Heat Sink Technology
- Low Cost Single Spool Turbofan
- High Density/High Energy Fuels

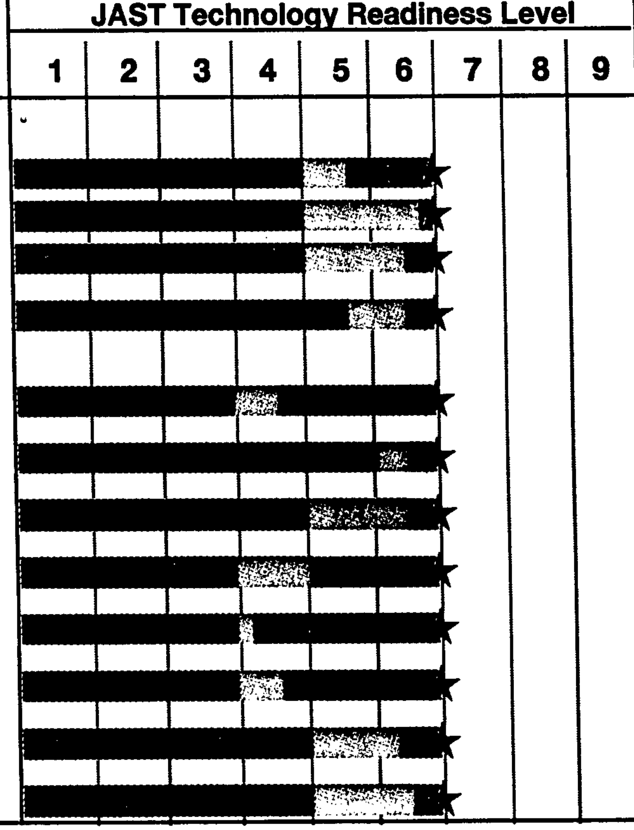
Avionics
- Environments/COTS
- On-Board Single Platform RDF/ESM
- Laser ID/DEW
- On-board LPI Active Multi-spectral Sensors
- Survivable Apertures

C4I
- Off-Board Targeting/ID Sensors
- Off-Board Sensors for Deconfliction
- 3-D Digital Maps in GPS Coordinates
- Intelligent agents
- Automated ATR/Cueing
- Secure LPI Data Links/HiData Rates

FWV Technologies Applicable to UCAV--Aeromechanics

This chart identifies the twelve technologies that were included in the QFD assessment under aeromechanics. Those technologies deemed to have application to UCAV SEAD vehicle concepts are indicated by an "" and are highlighted in bold print. All of the technologies except Integrated External Weapons Carriage and Laminar Flow Control (LFC) for Low Aspect Ratio Wing are considered applicable to a UCAV. It is expected that all weapons will be carried internally on the UCAV and the wing size of the UCAV will make it difficult to incorporate LFC technology.*

FWV Technologies Applicable to UCAV-- Aeromechanics



Thrust Area Technologies (Aerodynamics)	Demo Required	Required Investment $M Funded	Required Investment $M Unfunded
Exhaust System*	Flt Test (N)	1.85	4.64
Advanced Wing Planforms*	Flt Test (N)	10.46	1.69
Integrated Ext Weapons Carriage	Flt Test (N)	4.32	0.25
Compact Inlet System / Inlet - Aerostructural Integration*	Flt Test (N)	6.13	4.20
Active Flow Control (other than MEMS)*	Flt Test (N)	2.65	10.30
Tailless*	Flt Test (N)	5.42	2.24
Integrated Internal Carriage*	Flt Test (N)	2.46	1.73
Flow Control - MEMS*	Flt Test (N)	2.21	5.86
LFC for Low Aspect Ratio Wing	Flt Test (N)	0.17	2.26
Expandable Fuel Cell*	Flt Test (E)	0.20	3.63
Aero Synthesis Tools*	Ground Test	7.62	4.85
Wind Tunnel Test Productivity*	Ground Test	8.03	3.61
	Total	51.52	45.26

* Technologies Identified for Use on UCAV

LEGEND

Technology Readiness Level
- Jan. '97
- ★ Desired (2001First Flt.)
- Funded
- Unfunded

(C)--Flight Test Complete

(E)--Existing Test Aircraft

(N)--New Test Aircraft Needed

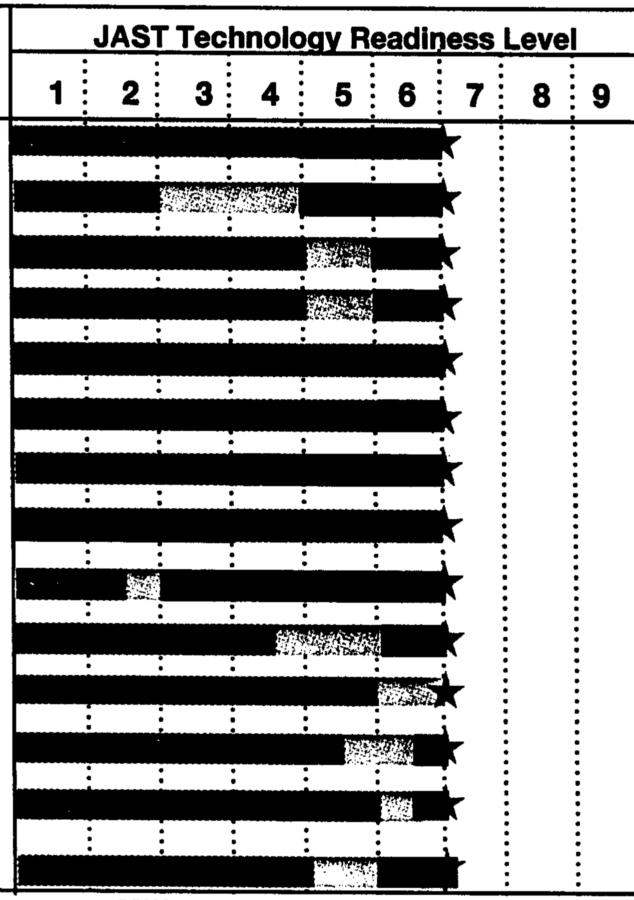
FWV Technologies Applicable to UCAV--Flight Controls

Fourteen FWV technologies were listed under flight controls in the QFD matrix. Half of those technologies were deemed to have application to UCAV SEAD vehicles while half were deemed only marginally applicable at best.

The seven directly applicable were selected because they could reduce production weight and/or cost, increase storage life, reduce development time, or provide necessary control functions. Specifically, ***Forebody Vortex Flow Control*** *and* ***Multi-Axis Thrust Vectoring*** *can reduce production cost and weight while providing improved vehicle control.* ***Power-By-Wire/Electric Actuation, COTS Hardware & Software, and Fiber Optic Gyro Inertial Measurement Sensors*** *technologies should significantly increase storage life.* ***Automated Closed-Loop Coupling*** *is required for UCAV command and control functions. Finally,* ***Flight Control Rapid Prototyping Processes*** *will provide fast development of the UCAV flight control configuration and allow quick modification of the design based on simulation and flight test data.*

The remaining seven listed technologies were not seen to be primary candidates for the UCAV based on the assumption that UCAVs will be smaller, have fewer control effectors, a shorter life, and fewer operational flights than a manned strike fighter. ***Multivariable Reconfigurable Control, Genetic Algorithm Flight Control Laws,*** *and* ***Intelligent Damage Adaptive Control System*** *technologies all address inflight reconfiguration to accommodate battle damage and require multiple control effectors.* ***Performance Seeking Aircraft Control*** *addresses optimal cruise and maneuver performance for a highly changing inflight weight and drag configuration, which probably is not the case for a UCAV.* ***Fly-By-Light Closed Loop Control,*** *which uses fiber optic cables instead of electric cables for communication and actuator control, may add cost and not significantly reduce wiring weight in a UCAV. Likewise,* ***Laser Optical Air Data System*** *technology, which is intended to reduce signature and improve sensor accuracy, may be too large, heavy, and costly to use in a smaller UCAV. Finally,* ***On-line Diagnostics for Two Level Maintenance*** *takes time to develop for each application and may not prove effective for a vehicle with long storage life and reduced operational flights.*

FWV Technologies Applicable to UCAV-- Flight Controls



Thrust Area Technologies (Flight Controls)	Demo Required	Required Investment $M Funded	Required Investment $M Unfunded
Forebody Vortex Flow Control*	Flt Test(N)	0.00	2.00
Multivariable Reconfigurable Ctrl	Flt Test(N)	1.20	4.00
Power-By-Wire/Electric Actuation*	Flt Test(N)	5.00	10.00
Fly-By-Light Closed Loop Control	Flt Test(N)	5.00	3.00
Performance Seeking Aircraft Ctrl	Flt Test(C)	0.00	0.00
Multi-Axis Thrust Vectoring (P/Y)*	Flt Test(E)	3.00	0.00
COTS Hardware & Software*	Flt Test(E)	20.00	0.00
Automated Closed-Loop Coupling*	Flt Test(C)	0.00	0.00
Genetic Algorithm Flt Ctrl Laws	Flt Test(N)	0.50	2.00
Online Diagnostics for Two-Level Maintenance	Flt Test(N)	1.50	10.00
Flt Ctrl Rapid Prototyping Processes*	Flt Test(E)	5.00	0.00
FO Gyro Inertial Measurement Sensors*	Flt Test(N)	1.00	0.50
Intelligent Damage Adaptive Ctrl Sys	Flt Test(E)	3.20	4.00
Laser Optical Air Data System	Flt Test(N)	7.40	4.50
Total		52.80	40.00

LEGEND

Technology Readiness Level
- Jan. '97
- ★ Desired (2001 First Flt.)
- Funded
- Unfunded

DEMO LEGEND

- C - Flight Test Complete
- E - Existing Test Aircraft
- N - New Test Aircraft Needed

* Technologies Identified for Use on UCAV

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PHANTOM WORKS

FWV Technologies Applicable to UCAV--Subsystems

The FWV subsystem technologies evaluated in the QFD assessment were placed into the eight major categories shown. All except the Advanced Landing Gear (in general) and Advanced Canopy technologies are considered applicable to a UCAV. The Advanced Landing Gear technology includes not only light weight gear which have more applicability to heavier vehicles but also load alleviation and oil bath lube which are not considered necessary for a UCAV. However, it also includes improved shimmy prediction and improved plating systems which will provide some benefit for a UCAV. The Extended Tire Life technology is also considered applicable to a UCAV. This tire development technology will reduce maintenance support even though the UCAV may spend considerable time in storage.

FWV Technologies Applicable to UCAV-- Subsystems

Thrust Area Technologies (Subsystems)	JAST Technology Readiness Level									Demo Required	Required Investment $M	
	1	2	3	4	5	6	7	8	9		Funded	Unfunded
Power By Wire/ Electric Actuation*								(2)		Flt Test (N)	18.1 (3)	5.38
Integrated VMS/Diagnostics*										Flt Test (N)	4.0	7.5
Advanced Landing Gear										Flt Test (N)	1.3	3.1
Extended Tire Life*										Flt Test (E)	6.7	1.0
Energy Management Systems*										Flt. Test (N)	71.5 (1)	3.2
- J/IST (TEMM)										Grnd Test (N)	50.1	0.0
- Other										Flt Test (N)	21.4	3.2
Aircraft Survivability*										Flt Test (E)	31.5	1.7
Advanced Canopy Technology										Flt Test (N/E)	1.6	0.7
Subsystems Virtual Design*										Analysis	2.5	0.0
										Total	137.2	22.58

* Technologies Identified for Use on UCAV

LEGEND

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(1) Energy Management Systems includes J/IST TEMM costs as shown, SITE-M, Integrated Thermal Energy Management and Advanced Fuels.
(2) PBW for UAVs is low risk
(3) Includes J/IST direct power generation costs.

FWV Technologies Applicable to UCAV--Structures

Six of the ten FWV structures technologies were deemed to have application to UCAV SEAD vehicles. The Active Aeroelastic Wing technology was not include due to the expected small size of the the UCAV vehicles and the simplicity of the wing section

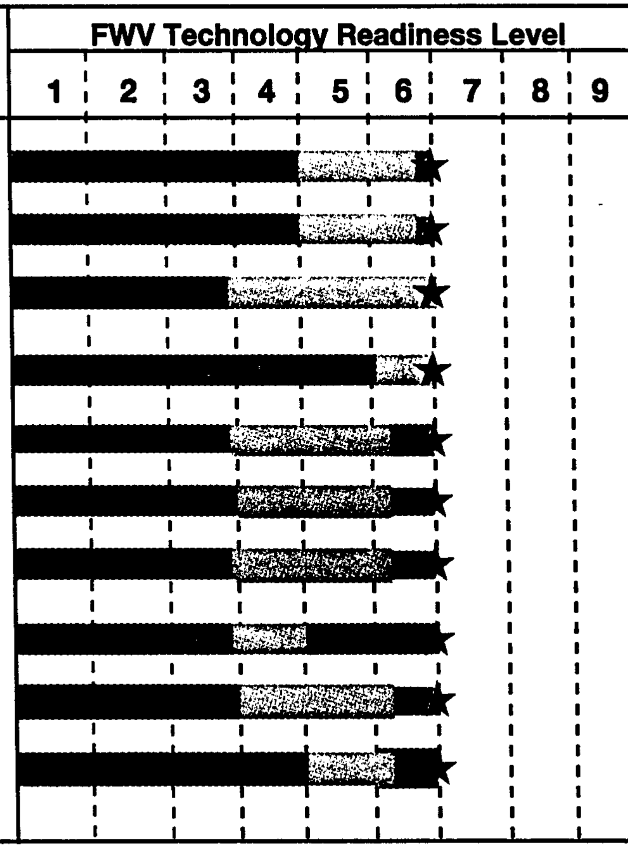
Unitized metallic substructures would be used to provide hard points for wing attachments and a frame which would provide some bend-not break capability for those components. which are to be crash survivable. In order to reduce cost, advanced welding technologies like friction stir welding would be used to assemble this framework and substructure. Where feasible, cast components would be used to further reduce the cost of the vehicle.

Low Temperature curing composite material have been developed which do not require autoclave processing and can be assembled using foam core as an inner surface tool for both upper and lower skins. if the wing does not store fuel, then the foam can be left to carry shear loads between surfaces and only forward and aft spar and inner and outer ribs will be required for the wing sections.

Design for manufacturing/assembly techniques would be used to minimize joints and fastener requirements and to insure the matched mating surfaces of the parts for easier assembly.

In addition to the use of a metallic cage for attachment of critical survivable components, stitched/RFI composites would be used on external skins wherever additional survivability was desired. These skins are not only impervious to ground handling loads, but also provide breakaway capability under shock loading to reduce mass and damage in crashes.

FWV Technologies Applicable to UCAV-- Structures



Thrust Area Technologies (Structures)	Demo Required	Required Investment $M Funded	Required Investment $M Unfunded
Unitized Metallic Substructures*	Grnd Test	$6.5-46M	$1.0-3.0M
Integrally Stiffened Composites*	Grnd Test	$6.5-46M	$1.0-3.0M
Active Aeroelastic Wing	Flight Test (E)	$11.8M	$0.0M
Design for Manufacturing *	Analysis	$7.5M	$0.0M
Survivable Structures*	Grnd Test	$8.5M	$2.0M
Inspection / NDI	Grnd Test	$4.8M	$1.5M
Repair Technologies	Grnd Test	$20.0M	$5.0M
Conformal Antennae*	Grnd/ Flt Test (E)	$1.0M	$2.0M
Active Load/Buffet Alleviation	Flight Test (E)	$1.0M	$7.0M
Exhaust Washed Structures*	Grnd Test w. Engine (N)	$24.0M	$6.0M
	Total	**$91.6M**	**$25.5M**

* **Technologies Identified for Use on UCAV**

LEGEND

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Summary

The objectives of Block 1/Phase 1 of the FWV Demonstration program have been achieved. Namely the identification of high payoff technologies that will lead to achievement of the FWV Sub Area goals. In addition, the validation requirements for each technology have been defined in terms of the type of demonstration needed to achieve a Technology Readiness Level (TRL) of Six. Also, the investment required, both currently funded and where applicable unfunded, to achieve a TRL of Six have been defined. Finally, Boeing Seattle and Boeing Phantom Works are in the process of integrating their respective Fighter/Attack AATPs into a combined Boeing AATP which may result in a reduction in the unfunded investment requirements. Finally, FWV Technologies applicable to a UCAV have been identified.

Summary

- **Block 1--Phase 1 Objectives of the Fixed Wing Vehicle Demonstration Program Achieved**
  - Technologies showing the greatest potential for achieving the FWV Sub Area Goals have been identified
  - High-Payoff Technology validation requirements and investment cost defined
- **Three Sets of High-Payoff Technologies Defined**
  - Set #1 Addresses the combined set of six cost and performance goals
  - Set #2 addresses the three cost goals
  - Set #3 addresses the three performance/weight goals
- **High-Payoff Technology Demonstration Requirements Defined**
  - Type of Demo (Ground/Flight/Analysis) for each Technology to Reach TRL #6
  - Investment Requirements (Currently Funded and Unfunded)
- **FWV Technologies Applicable to UCAV SEAD Vehicle Identified**